EFFECT OF VARIETY, PLANTING MATERIAL AND IN-GROUND STORAGE ON SWEETPOTATO WEEVIL (*Cylas spp*) POPULATION, DAMAGE AND YIELD OF SWEETPOTATO *(Ipomea batatas)* (Lam)

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A thesis submitted to the Graduate School in partial fulfillment for the requirements of the degree of Master of Science in Agronomy (Crop protection) of Egerton University

EGERTON UNIVERSITY

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DECLARATION AND RECOMMENDATION

Declaration

I declare that this is my original work and has not been presented for an award of a degree in this or any other university.

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DEDICATION

To my late mother in law Repher, who never went to school but encouraged me to continue with my studies. You gave me the spirit to fulfill my aspirations. The last time I came home to say bye before going back to the university, you asked me when I would be completing my studies. Little did I know that in a month's time you would collapse and join your husband. In memory of you, I dedicate this thesis.

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ABSTRACT

One of the major constraints to high sweetpotato (*Ipomea batatas* (L) Lam) production in Western Kenya is damage by sweetpotato weevil (*Cylas spp*). Lack of adequate clean planting material and extended in-ground storage period of more than one year have been reported to significantly reduce quality and yields of sweetpotatoes despite planting high yielding varieties. The objective of the study was to determine the effect of variety, type of planting material and in-ground storage period on sweetpotato weevil population density; damage and yields of sweetpotatoes. The field experiment was conducted at Bukura Agricultural College, Kakamega over two seasons June, 2009 – May, 2010 and September, 2009 – August, 2010. Sweetpotato variety at two levels (SPK 004 and SPK 013), in-ground storage period at four levels (150, 210, 270 and 330 days after planting) and types of planting materials at three levels (sprouts, vine tips and vine middle) were used as main plot, sub plot and sub sub plot treatments in a split – split plot design in a randomized complete bock arrangement with three replicates per treatment. Sub sub plots were measuring 2 m x 4 m and consisted of four ridges 1 m apart. Data were collected at each harvest time and during each in-ground storage period, data on total number and total weight of harvested vines and storage roots, number and weight of infested vines and storage roots and weevil population on vines, crowns and storage roots were recorded. The results showed that yields of vines were significantly ($P<0.05$) higher (10 tons/ha) during season II for both varieties. Variety SPK 013 significantly ($P<0.05$) gave higher yields of vines during both seasons and higher yields of storage roots during season I than SPK 004. Where as, SPK 004 had higher weevil population density and higher damage than SPK 013 on both vines and storage roots. In-ground storage period at 330 days after planting (DAP) significantly ($P<0.05$) had higher yields not different from 210 DAP and 270 DAP while 150 DAP had the lower yields of vines and storage roots during both seasons. The lowest weevil density and damage were recorded at 150 and 210 DAP while 330 DAP had the highest weevil density and damage of vines and storage roots during both seasons. Planting sweetpotatoes using vine tips significantly ($P<0.05$) had greater yields of storage roots than sprouts during both seasons, but did not differ significantly from vine middle during season II. Weevil population and damage was high on vine middle and low on sprouts and vine tips during both seasons.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ACRONYMS AND DEFINATION OF TERMS

FAO	Food and Agriculture Organization
CIP	International Potato Center
IITA	International Institute of Tropical Agriculture
IPM	Integrated Pest Management
MOA	Ministry of Agriculture
ANOVA	Analysis of Variance
IPPM	Integrated Production and Pest Management
FFS	Farmers Field Schools
FAOSTAT	Food and Agriculture Organization Statistics
RCBD	Randomized Complete Block Design
DAP	Days After Planting
KARI	Kenya Agricultural Research Institute
CGIAR	Consultative Group on International Agricultural Research
AVRDC	Asian Vegetable Research Development Center

CHAPTER ONE

INTRODUCTION

1.1 Importance and Production of Sweetpotato

Sweetpotato (*Ipomoea batatas* (L) Lam.) is a native of Central America grown worldwide as an important food security crop. It ranks fifth among all staple crops worldwide (FAO, 2005). In East Africa, sweetpotato is grown all the year-round by resource-poor farmers, mostly for household consumption and as a source of family cash income. In Kenya maize is the staple food but sweetpotato is an important secondary food crop mainly grown by women (Maling'a, 2000). Nutritionally some varieties that are orange fleshed provide vitamin A (Ndolo *et al.*, 2001). In Western Kenya, sweetpotato play an important role in the diet of many people especially, in seasons of maize crop failure (Mutuura *et al.*, 1992). Studies by Owori and Hagenimana (1998) showed that sweetpotato is mainly used as a food component which can be boiled, mashedwith beans (mshenye) or roasted among many rural farmers in Kenya. Sweetpotato can also be processed and be used in enriching other products (Nungo, 2004). Gathaara *et al.* (2000) survey showed that SPK 004 is preferred for use as relish (vegetable stew) and mashed food (mshenye/Irio).

World production area under sweetpotato for the last 30 years has declined from 15 million hectares to 9.7 million hectares. Production in Africa has expanded with production of 11. million tons in 2002 and 12. million tons in 2006 having a yield progress of 4 to 4.5 t ha^{-1} (Andrade *et al.*, 2009). Uganda is the leading producer with 2.7 million tons followed by Nigeria 2.5 million tones, Rwanda 1.3 million tons and Tanzania 0.95 million tons per year (CABI, 2005). In Kenya, production expanded from 60,000 hain 2002 to70, 000 ha in 2006 while the yields increased from 0.514 million tons to 0.769 million tons respectively (Andrade *et al.*, 2009). During 2010 the area was 42,000 ha with production of 0.323 million tons (MoA, 2011). Fifty percent (50%) of Kenya's sweetpotato production is in Western Province (Mutuura *et al.*, 1992).

1.2 Constraints to Sweetpotato Production

Sweetpotato production is constrained by several factors that include; lack of improved healthy planting materials, poor agronomic practices, drought, diseases and pests (Ewell, 1990). The major insect pests that undermine sweetpotato production are sweetpotato weevil *Cylas spp* (Andrade *et al.*, 2009; Nderitu *et al.*, 2009; Ebregt *et al.*, 2007, 2005; Smit, 1997). The most important species are *Cylas brunneus*, (Olivier) *Cylas puncticollis* (Fabricius) and *Cylas formicarius* (Fabricius) (Coleoptera: Apionidae). The two common species *C. brunneus* and C. *puncticollis* are the most important in East Africa and are widely spread in all sweetpotato growing regions in Western Kenya (Smit, 1997b; Smit and Matengo, 1995). But later, studies by Smit, (1997a) also confirmed that *C. formicarius* is also in coastal parts of Kenya at Msabaha.

Sweetpotato weevil damage results in low yields of storage roots, poor quality damaged storage roots for consumption (Sato *et al.*, 1981) and unhealthy infected planting materials. Poor quality storage roots also create problems associated with marketing (CIP, 2007). Studies have reported yield losses ranging from 5% to 100% in areas where the weevil infestation is prevalent (Mullen, 1984). Surveys carried out in Kenya and Uganda on sweetpotato weevils *C. brunneus* and *C. puncticollis* indicated that they can affect the crop throughout the year (Ebregt *et al.*, 2005, 2004b; Smit, 1997a, 1997). According to Maling'a (2000); Smit, (1997a, 1997); Smit and Matengo, (1995), weevils are more abundant and injurious during the dry season. Cracks formed during the dry period make the roots to be exposed thus accessible for weevil infestation (Stathers *et al.*, 2003; Maling'a, 2000).

Most farmers who plant sweetpotato often store the roots in-ground on plants only accessing them through piecemeal harvesting (Smit and Matengo, 1995; Smit, 1997b; Ebregt *et al.*, 2004b). Several times during the growing period, farmers remove harvestable large storage roots from the plant without uprooting the plant itself but sweetpotato roots are extremely vulnerable to weevils if left unharvested (CIP, 2008). Smit (1997b) observed that piecemeal harvesting reduces sweetpotato weevil infestation but the yields are low during the subsequent harvests. Symptom of infestation by sweetpotato weevil is yellowing of the vines, tunnels inside the stems that extend inward causing vine to darken, crack, or collapse. The infested roots have long twisted, frass-filled tunnels and are often spongy in appearance. The roots also develop secondary infections of root rots (dark in color) and changes in quality with terpenoids (Sato *et al.*, 1981) and off flavours. In most countries, chemical control is not cost-effective for subsistence farmers as weevil life stages take place underground. The crop is of low value and cultural control measures are the best strategy for small-scale sweetpotato growers.

1.3 Statement of the problem

Sweetpotato is an important food security crop for farmers particularly women in Western Kenya during the dry season when other food are scarce. Sweetpotato weevil is the most serious pest of sweetpotato with reports of losses in Kenya being estimated at 65% but in Western Kenya, loss is recorded at 50%. Most farmers store the roots in-ground throughout the year for supply of fresh storage roots and source of planting materials which predisposes the roots to sweetpotato weevil infestation. Prolonged dry season experienced in Western Kenya lead to shortage of planting materials forcing farmers to use any available planting materials. The yields quality and quantity of sweetpotato have declined despite the use of new high yielding and nutritious varieties due to infestation by sweetpotato weevils and inadequate clean planting materials among other production constraints.

1.4 Objective

1.4.1 Broad objective

The general objective of this study is to reduce yield loss of sweetpotato attributable to sweetpotato weevil (*Cylas spp*).

1.4.2 Specific objectives

i) To determine the effect of variety on sweetpotato weevil population density, vine and root damage and yield of sweetpotato.

ii) To determine the effect of in-ground storage period on sweetpotato weevil population density, vine and root damage and yields of sweetpotato.

iii) To determine the effect of type of planting materials on sweetpotato weevil population density, vine and root damage and yields of sweetpotato.

iv) To determine interaction effect between variety, type of planting material and in-ground storage period on sweetpotato weevil population density, vine and root damage and yields of sweetpotato.

1.5 Hypotheses

i) Variety has no effect on sweetpotato weevil population density, vine and root damage and yields of sweetpotato.

ii) Type of planting materials has no effect on sweetpotato weevil population density, vine and root damage and yields of sweetpotato.

iii) In-ground storage period has no effect on sweetpotato weevil population density, vine and root damage and yields of sweetpotato.

iv) Variety, type of planting material and in-ground storage period have no effect on weevil population density, vine and root damage and yields of sweetpotato.

1.6 Justification

Sweetpotato is well suited for food security; as it stores well in-ground, provide food in April and May when there is scarcity of food and can produce more edible energy per hectare per year than wheat, rice and cassava (Woolfe, 1992). Sweetpotato is an important staple food eaten for lunch or dinner as a main meal (Hagenimana and Owori, 1996). Studies by Ndolo *et al.* (2001) and Tumwegamire *et al.* (2004) showed that, sweetpotatoes are rich in carbohydrate and some varieties are rich in vitamin A especially the orange fleshed sweetpotato cultivars being disseminated to growers in Western Kenya.

Sweetpotato production is constrained by sweetpotato weevil infestation (*Cylas spp*) causing substantial quantitative and qualitative loss varying in magnitude with yield loss of up to 100% yield loss with weevil damage increasing the longer the crop remains unharvested (CIP, 2008). In a priority-setting research survey by Fugile (2007) management of weevils was the highest ranked need. Most farmers store the crop in-ground as sweetpotato can be maintained in the ground for piecemeal harvesting to supply fresh storage roots and planting materials continuously throughout the year (Maling'a, 2000; Ebregt *et al.*, 2007). Lack of clean type of planting materials is experienced at the beginning of the planting season, as prolonged dry season is followed by shortage of planting materials and most farmers pick any planting material from existing crop including from neighbours without an opportunity to select cleaner type of planting material. Despite the high yielding varieties being advocated for in Western Kenya where clean planting materials have been disseminated to the farmers, still weevils are a problem as farmers still store the crop in-ground and pick planting materials from neighbours.

Intensive studies conducted and documented information indicate that; in-ground storage of sweetpotato increase magnitude of sweetpotato yield loss due to sweetpotato weevil infestation (Smit, 1997a; Ebregt *et al.*, 2007b), the type of planting material has an effect on weevil infestation and yields of sweetpotatoes (Alcarzar *et al.*, 1997; Nasir *et al.*, 2003; Tewe *et al.*, 2003;

Alcay, 2007; Novak, 2007; Andrade *et al.*, 2009) and varieties of sweetpotatoes have different resistance to sweetpotato weevils (Moa, *et al.*, 2001; Kabi *et al.*, 2001). However, no detailed study has been conducted to evaluate susceptibility to sweetpotato weevil on the improved varieties being disseminated to farmers, the optimum in-ground storage period and the type of planting material. Therefore, there is need to evaluate the improved varieties, develop an in-ground storage harvesting protocol and type of planting material with lower sweetpotato weevil population density and higher yields of sweetpotatoes.

CHAPTER TWO

LITERATURE REVIEW

2.1 Description and Distribution of Sweetpotato Weevil

Sweetpotato weevil is in the genus *Cylas* (Coleoptera: Apionidae) (Anota and Odebiyi, 1984; Chalfant *et al.*, 1990; Smit, 1997a) contains three species namely *Cylas formicarius* (Fabricius), *Cylas puncticollis* (Fabricius) and *Cylas brunneus* (Olivier) (Woolfe 1991). Several studies have shown that only *C. puncticollis* (Fabricius) and *C. brunneus* (Olivier) have been confirmed to commonly occur in Kenya Woolfe (1991), Smit and Matengo (1995); Nderitu *et al.*, (2009)). However, later studies by Smit, (1997) found out that also *C. formicarius* (Fabricius) is at Msabaha in the coastal region of Kenya. Adult weevils are elongated, smooth, and shiny with an ant-like snouted beak but species can be differentiated by size and colour (Smit, 1997). *C. formicarius* are small with a bluish black abdomen and a red thorax, *C. puncticollis* are black and large, *C. brunneus* are small either black or brown (Smit, 1997). Infestation of sweetpotato weevil *Cylas spp* is worldwide with reports in Asia, Africa, Central America and Caribbean, North America, South America and Oceania (CABI, 2005). Infestation of sweetpotato weevil in Kenya, is at 65% of these, 67% is in the Central highlands, 66% in the Coastal region and 50% in Western Kenya (Mutuura *et al.*, 1992).

2.2 Life Cycle of Sweetpotato Weevil

Sweetpotato weevil undergoes complete metamorphosis i.e. egg, larva, pupa and adult. The egg is oval yellowish-white and hatch after three to seven days depending on temperatures (Mullen, 1981; Sathula *et al.*, 1997). A female can lay two to four eggs per day has a fecundity mean of 179 eggs per female (Mullen, 1981; Sathula *et al.*, 1997. Smit (1997) working under tropical conditions determined that *C. puncticollis* had fecundity of 103 eggs, shorter life cycle of 20-28 days and life span of 140 days, while *C. brunneus* had fecundity of 100 eggs, life cycle of 31-41 days and life span of 92 days. The female lays eggs singly in the vines or exposed roots. The hatched white curved larvae burrow in the stems or exposed roots and feed for two to three weeks, pupate and the adult emerge after seven days (Sathula *et al.*, 1997). Under favourable conditions sweetpotato weevils can produce 13 generations a year, can live three to four months and can produce up to an average of 100 eggs per female during its lifetime Therefore, population densities build up in the course of the growing season is very high.

2.3 Infestation and Dispersal of Sweetpotato Weevil

Sweetpotato weevils *Cylas spp* infest both the roots and the mature sections of the vines of sweetpotato. Literature surveys indicate that, movement of larvae via infested roots or vines is the most likely route of dispersal and spread for the weevils (Sutherland, 1986b; Kawamura, 2007). Infestation is by female weevils laying eggs on vines at the base of the sweetpotato plant or accessing the roots through cracks to lay eggs. Studies by Alcazar *et al.* (1997) indicate that infested materials contribute greatly to the increase in sweetpotato weevil population since 95% of sweetpotato weevils' eggs are laid in the first 35 cm of the stem from the base and that weevils prefer the stems for laying eggs. Hence planting a woody portion will increase growth and development of sweetpotato weevil. Planting a vine tip cutting of 30cm has been reported to be free of weevils (Smit and Matengo, 1995; Talekar, 1995). A survey by Nasir *et al.* (2003) in Java indicated that low yields in sweetpotato is caused by low quality planting materials as most farmers get vine cuttings from their previous crop or neighbours which are already infested by sweetpotato weevil.

Infestation of the crop is also through contamination when sweetpotato weevils migrate from neighbouring fields when the crop is planted next to an infested field. Studies by Smit (1997) and *et al.*, (2005) indicated that maximum dispersal distance is 120m for *C. puncticollis* and 80m for *C. brunneus*. Most farmers in western Kenya do not practice field sanitation (Smit, 1997; Maling'a, 2000) because they leave the crop residues in the field which also serve as a means of sweetpotato field infestation.

2.4 Symptoms and Damage by Sweetpotato Weevil

Studies show that the weevil spends its entire life cycle on the host plant. Both larval and adult stages damage the roots and vines but the main damage is done to the roots by the larvae. The larvae feed by tunneling in the vines and roots and pupate inside the stems and roots. The larvae feed in the roots and stems, producing larval tunnels and later, pupal chambers. Stem damage is believed to be the main reason for yield loss because of the damage to the vascular system through feeding and larval tunneling. Sweetpotato weevil feeds inside the vine, causing malformation, thickening and cracking of the affected vine. Heavy infestation of vines with high damage levels in vines (at vine base) could affect the storage roots and consequently a reduction in total yield and root size (Sutherland, 1986b; Smit, 1997a). Powell *et al.* (2001) found out that the period the weevil start to invade the crop above soil surface and the proportion of vines damaged increase with time. The infestation by the weevils increase steadily up to and including final harvest time (Powell *et al.*, 2001). At this moment farmers should check their crop for weevil infestation as it can lead to the field becoming a source of infested planting material.

Kays *et al*, (1993) found out that roots are attacked both in the field and during storage and the pest can breed successfully inside the roots with repeated cycles if there is sufficient food available. Relatively, minor damage can both reduce yield and render infested roots unmarketable due to the presence of feeding marks, oviposition holes and secondary infection where the roots rot (Sutherland, 1986b; Stathers *et al.*, 2003). Weevil-infested roots emit offensive odours due to the presence of terpenes produced by the insects which raise the level of phenolic compounds in the roots rendering them unpalatable for human or animal consumption (Sato *et al.*, 1981; Stathers *et al.*, 2003). Studies by Ebregt *et al.* (2007b) showed that weevil damage of storage roots is less with piecemeal harvesting it also increases the quality of the storage roots for human consumption and commercial purposes. Root shrinkage occurs due to loss of water through feeding or oviposition cavities made by the weevils.

2.5 Control Methods

2.5.1 Cultural Control

Majority of African farmers still rely on indigenous pest management approaches to manage pest infestation in their farms (Abate *et al*, 2000). Cultural practices, such as crop sanitation and avoidance of adjacent planting of successive crops are considered the most important components (Smit and Matengo 1995). Crop rotation has been reported to reduce weevil infestation (Ebregt *et al.*, 2004b; 2005; 2007b). Crop rotation is a practice where sweetpotatoes are planted in different sections of the field / plot in a two or three year rotation cycle with other crops not of the same species with sweetpotato. Literature surveys available show that, sweetpotato on fallows result in lower weevil root damage (Powell *et al.*, 2001). However, crop rotation and spatial arrangements to avoid neighboring crops of the same species are not practiced, thus high infestation frequencies and abundances of the sweetpotato weevil (Ebregt *et al.*, 2004a). Studies by Muhanna and Kiozy (1996) showed that a cultural method of hilling up twice, intercropping with legumes or hilling up once and application of farm yard manure reduced weevil damage to crowns of sweetpotato weevils.

Other cultural practices include selection of deep-rooting cultivars, with long necks between the roots and the stems are less susceptible as the adult weevil cannot burrow downwards more than 1 cm (Smit, 1997; Kabi *et al.*, 2001; Stathers *et al.*, 2005) thus weevil adults find it hard to access to the roots for egg oviposition. Planting early-maturing cultivars that can escape serious damage is also a noble option. Strip cropping with maize reduce weevil infestation in vines and storage roots (Rajasekhara, 2005; Nedunchezhiyan *et al.*, 2010). Earthing up of plants during weeding (every 4 to 6 weeks) particularly those cultivars with the tendency to push out of the ground as this places the roots deeper and out of reach of the weevils .Studies by Odongo *et al.*, (2003) showed that re-hilling to cover soil cracks and exposed storage roots, removal of all plant debris and volunteer plants after planting with non-infested material will reduce weevil infestation.

Type of planting material used could also influence weevil incidence in sweetpotato crop. Sweetpotato is mainly established through vegetative propagation; use of vine cuttings and sprouts from roots. Studies by Novak, (2007) and Alcoy, (2007) showed that, method of seedling production has significant effect on the yields of sweetpotatoes. Nasir *et al.*, 2003 and Andrade *et al.*, (2009) observed that, most farmers get vine cuttings from previous crop and prefer use of apical cuttings of young vines but use older basal vines when young vines are unavailable. Sweetpotato vine tips and sprouts used as planting materials establish better than vine middle and basal vines (Tewe *et al.*, 2003; Alcoy, 2007) and have reduced weevil damage (Alcoy, 2007). Young portion of shoots used as planting materials minimize transfer of eggs and larvae to new crops (Stathers *et al.*, 2005). Studies indicate that sprouts and vine tips are less infected by weevils as weevil feed and develop on mature stems (Alcazar *et al.*, 1997). In the tropics, shortage of planting materials caused by prolonged dry season lead to use of older basal vine cuttings from existing crop.

2.5.2 Biological Control

There are no recorded releases of parasitoids or predators in Africa (Jansson *et al.*, 1990). Studies on bioassays to evaluate the pathogenicity of the fungal pathogens *Metarhizium anisopliae* and *Beauveria bassiana* against *C. puncticollis* has been conducted by Lobo-Lima (1990). Mortality rates obtained were encouraging but their habitat makes them less accessible to predators and parasitoids. Potential candidates for use as biological insecticides include *B. bassiana* and *M. anisopliae*. Isolates of the former have been collected from laboratory reared adults originally collected in Kenya (Allard *et al.*, 1991). Extensive laboratory investigation indicated that entomopathgenic fungi have been found to have a positive effect on feeding, fecundity and egg viability of *C. puncticollis* (Nyamasyo *et al.*, 2008).

2.5.3 Host-Plant Resistance

Plant host resistance is important in management of insect pest (Rajasekhara, 2005). Work to develop host resistance has resulted in cultivars with moderate levels of resistance. According to studies by Moa *et al.*,(2001) and Kalhi *et al.*, (2001), the mechanism of resistance based on antixenosis in the sweetpotato is responsible for sweetpotato weevil resistance. Some sweetpotato genotypes are uninjured while other genotypes roots and vines are damaged (Stathers *et al.*, 2003; Moa *et al.*, 2004; Muyinza *et al.*, 2007). For instance in certain varieties during drought when the roots are stressed, the roots had more eggs and feeding punctures. Identification of biochemicals from sweetpotato that influence weevil behaviour is a new approach for resistance breeding (Nottingham *et al.*, 1987). Globally, several attempts have been made to breed for resistance to sweetpotato weevil *Cylas spp* (Talekar, 1989). Breeding work on production of sweetpotatoes that can resist weevil attack and boost yields is ongoing. There is a promising germplasm from a combined work of INIVIT and CIP which have been identified and trials have shown that it can yield up to 34 tones with weevil loss of 4-5% without any control measures (CIP, 2000).

Despite years of intensive research, varieties with resistance to *C. puncticollis* and *C. brunneus* are not available despite the progress in finding weevil resistant components in some varieties (Stevenson *et al.*, 2009). Cultivar characteristics have influence on the incidence of weevils and degree of damage to sweetpotato roots. Cultivars susceptible to attack by sweetpotato weevil have terpenoids located in the outer periderm of the roots (Nottingham *et al.*, 1987; Sato *et al.*, 1981), which increase the ovipository behaviour of adult females. A study conducted in Nigeria by Anota and Odebiyi, (1984) indicated that *C. puncticollis* raised on resistant cultivars had a low survival rate in all life stages, smaller body weights and a longer developmental period. So far, none has been done in Kenya.

Resistance breeding is difficult because resistance characters in sweetpotatoes are identified under polygenic inheritance which includes fleshy root density, dry matter and starch content, root depth, vine thickness and root chemistry (Allard *et al.*, 1991). At present attention is on the use of genetically modified organisms. Genetic engineering is a more viable option that can offers a means to introduce resistant genes into sweetpotato, *Bacillus thuringiensis* (Bt) genes have been used against *C. puncticollis*, *C. brunneus*, and *C. formicarius* (Andrade *et al.*, 2009). An *in vitro* insect feeding assay indicated that diet formulations including specific Bt proteins were highly toxic to the three weevil species (Moar *et al.*, 2007).

2.5.4 Chemical Control

Worldwide, most sweetpotato farmers are resource poor who produce sweetpotato on small pieces of land thus uneconomical to use pesticides to control sweetpotato weevil. In developing countries such as Kenya, control of sweetpotato weevil chemically is not cost effective as the target larvae feed in the storage roots in the ground or inside the woody base of the stems. Therefore, there is no effective chemical control of the larvae, or other stages found within the plant tissue (Allard *et al.*, 1991). However, Maling'a, (2000) reported that dipping vines in a diazinon solution prior to planting combined with foliar sprays after planting reduced sweetpotato weevil damage. Systemic insecticides are costly as in Cuba farmers' sprayed 12-15 each growing season; these also pose the risk of residual contamination of the roots and environment (CIP, 2000).

2.5.5 Integrated Pest Management

Worldwide, different control methods when employed singly cannot control sweetpotato weevils when the populations are high especially during the dry periods. Integrated pest management (IPM) may be the only alternative control (Smit, 1997). This is a practice where several measures are combined sustainably to control the sweetpotato weevil. The package of IPM to use should be compatible to each other. According to (CIP, 2000), use of predatory ants *Pheidole megacephala* and *Tetramorium guineence*, fungus *Beauveria bassiana*, sex pheromones and planting short season cultivars in a pilot IPM trial in Cuba showed that weevil damage was reduced from 45% to 6%. Experiments have also been conducted to evaluate the integrated effect of sex pheromone and insecticide in the control of sweetpotato weevil where pheromone-baited traps placed in combination with the pre-planting application reduced damage of roots by 75.4% (Hwang and Hung, 1991). Studies conducted in Uganda showed that use of piecemeal harvesting a common practice by farmers reduced weevil infestation by 10% (Ebregt, 2007b).

2.5.6 Use of Pheromones

Extensive studies on use of pheromones show that male weevils can be lured and weevil populations reduced (Smit *et al.*, 2001). Mass-trapping of both African species reduces numbers of males without any beneficial effects on yield or infestation rates. Studies by Downham *et al.* (2001) under tropical conditions on *C. puncticollis* and *C. brunneus* by mating-disruption using the synthetic sex pheromone found out that there was low infestation in plots treated with the pheromone.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Study area

The field experiments were conducted at Bukura Agricultural College in Kakamega district, Western Province of Kenya in two consecutive growing seasons. End of long rains (June, 2009 to May, 2010) and onset of short rains September, 2009 to August, 2010. Bukura lies at an altitude of 1463 m above sea level, receives an average rainfall between 1500mm to 1800mm with a mean maximum and mean minimum temperature of 25°C and 22°C, respectively with an agro-ecological zone lower midland 1(Map 1). The soil type is ferresols well drained dark and friable, texture is sandy loam and soil pH of 4.8 (Jaetzold *et al.*, 2007). Bukura has a bimodal rainfall pattern with long rains between the month of March – June and short rains August – October. Monthly rainfall data was obtained from Bukura institute metrological station during the cropping season. (Appendix 1)

MAP 1 : MAP OF AGRO - ECOLOGICAL ZONES AND SOILS OF KAKAMEGA

Source: Jaetzold *et al.*, 2007

3.2 Treatments, Experimental design and Field layout

The experimental treatments were organized in a split – split plot design in a randomized complete block arrangement replicated three times per treatment per season. Factors under study and their levels tested were as follows;

Variety (main plot)

1. SPK 013;

   High yielding improved but late maturing (5months) white fleshed, high dry matter variety grown in Western Kenya and speculated by farmers to have low susceptibility to sweetpotato weevils (Plate 1).
2. SPK 004;

   Improved early maturing (3-4 months) orange fleshed, moderat dry matter variety commonly grown but very susceptible to sweetpotato weevils (Plate 2).

Plate 1: Sweetpotato variety SKP 013 Vines and Storage roots

Plate 2: Sweetpotato variety SKP 004 Vines and Storage roots

In-Ground Storage Period (Sub plot)

1. 150 DAP
2. 210 DAP
3. 270 DAP
4. 330 DAP

Type of Planting Materials (Sub sub plot)

1. **Sprouts;**

   These were planting materials grown from storage roots. Clean small storage roots from healthy plants at KARI Kakamega were planted in a nursery bed for 8 weeks. They were cut 30cm from growing tip (Plate 3).

2. **Vine tips;**

   These were vine portions cut 30cm from growing apical tip of the vines free of sweetpotato weevils (Plate 4).

3. **Vine middle;**

   These were vine portions cut 15cm from the crown base of the vines up to 30cm from the apical tip. The portions used were cut 30cm long from the crown base (Plate 5)

Plate 3: Planting material sprouts

Plate 4: Planting material, vine tips

Plate 5: Planting material, vine middle

The varieties, in-ground storage period and types of planting materials, randomly using random tables were allocated to main plots, sub plots and sub sub plots respectively (Appendix 2). Planting was done on plots which had four ridges spaced one meter apart and four meters long. The sweetpotatoes were harvested once they reached the number of growing days indicated in the treatments. Yield and yield components were measured for analysis, weevil damage on vine, crowns and storage roots were assessed using rating scale and weevil numbers counted and recorded.

At harvesting time, using destructive sampling technique (Stathers *et al.*, 2005), two inner ridges of each plot were harvested; vines were cut at 0.15m from the base above the soil level and counted to record stand count at harvest. Infested vines and crowns (vines and crowns which were thick, malformed cracking and with round holes) (Plate 6) and uninfested vines and crowns were separated counted and recorded. The vines were then put together, weighed (Plate 7) and recorded.

Swollen crown of sweetpotato with exit weevil hole

Plate 6: Infested vine crown

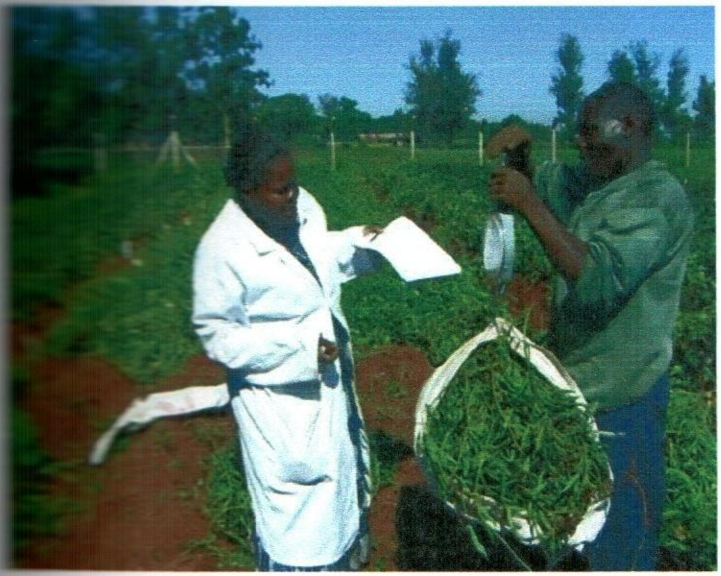

Plate 7: Weighing sweetpotato vines

Storage roots were uprooted manually, separated into those of marketable size (more than 3.5cm root diameter) and these of unmarketable size (less than 3.5cm root diameter) (Maling'a, 2000) then counted, weighed and recorded. Only marketable size storage roots were assessed for root damage where the clean storage roots/uninfested (Plate 8) and infested storage roots (Plate 9) were separated and weighed separately (infested roots were those roots with dark marks and round holes on the surface while those without were considered clean/uninfested).

Plate 8: Uninfested storage roots

Plate 9: Infested storage roots showing weevil emergence holes

[illegible] Experimental Variables

Plant stand count

At four weeks after planting and at harvest, plants from two inner ridges were counted to determine the number of sweetpotato plants that were established and those that survived during the growing period.

Yield of vines and storage roots

The number of vines and storage roots from two inner ridges per harvest plot were counted and weighed then yield calculated (plate 7).

Percent weevil incidence on vines crowns and storage roots

Infested vines, crowns and storage roots (plate 9) were separated form uninfested (Plate 8) counted and the data subjected to the formula;

$$\frac{\text{Number of weevil infested vines/crowns/storage roots from 2 ridges per plot}}{\text{Total number of vines/crowns/storage roots from 2 ridges per plot}} \quad \text{X } 100$$

Weevil population density on vines, crowns and storage roots

Five (5) infested vines, crowns and storage roots from 2 ridges per plot were randomly picked, sliced longitudinally and weevil live stages (larvae, pupa and adults) removed counted (plate 10) and then weevil population density calculated by the formula;

$$\frac{\text{Number of weevil counts in 5 infested vine/crowns/storage roots from 2 ridges per plot}}{\text{Total number of infested vine/crowns/storage roots from 2 ridges per plot}} \quad \text{X } 100$$

Severity of weevil damage

Five infested vines, crowns and storage roots from 2 ridges per plot were randomly picked from each harvest plot, visually examined to determine the amount of severity of damage and assessed using the following rating scale (Stathers *et al.*, 2003):

Rate	**Percentage range (%)**	**Damage**
1	0	No damage
2	1 – 25	Slight damage
3	26 – 50	Moderate damage
4	51 - 75	Severe damage
5	76 - 100	Very severe damage

Plate 10: Infested storage root cut in pieces to remove sweetpotato weevil live stages

3.4 Data Analysis

Data on weevil population density, weevil incidence, mean numbers of marketable, unmarketable, infested and total storage roots, vines and crowns, were subjected to square root (x + 1) transformation to stabilize the data. Analysis of variance was done using SAS software and means separated by use of Least Significant Difference (LSD) (P<0.05) (SAS, 2009).

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Effect of variety, in-ground storage period and type of planting material on weevil infestation and yields of sweetpotato vine

4.1.1 Variety, in-ground storage and type of planting materials effect on number and yield of sweetpotato vines

Yield of vines significantly (P<0.05) differed between the two varieties during both seasons. The vine yields were higher during season II by 10 tones than season I (Tables 4.1 & 4.2). This could partially be attributed to high amount and even distribution of rainfall during season II that encouraged vigorous growth of both varieties (Appendix 1). SPK 013 significantly (P<0.05) had higher yield of vines than SPK 004 during both seasons. The yields of SPK 013 were 25% - 27% higher than SPK 004 during both seasons (Tables 4.1 & 4.2). Thick shoots and broad leaves of SPK 013 were associated with high mean vine weight where as SPK 004 had thin leaves and thin stems that weighed less (Jannson *et al.*, 1990; Ndolo *et al.*, 2001; [illegible] *et al.*, 2003). Delay to harvest significantly (P<0.05) resulted in different yields of vines which increased the longer they were in-ground. The yields of vines were significantly (P<0.05) higher at 330 DAP during both seasons which was not significantly different from 270 DAP and 210 DAP while 150 DAP had the lowest yields of vines. This is not in line with studies by [illegible] *et al.*, (2001) which indicated that vine yield reach maximum/peak at five months after planting and then gradually decrease. Type of planting material did not have significant difference on yields of vines during both seasons.

Number of vines at harvest did not differ between varieties and among in-ground storage period during season I. However, during season II, the highest number of vines at harvest was recorded at 330 DAP but did not significantly differ from 150 DAP. The lowest number was significantly (P<0.05) at 210 DAP which did not differ from 270 DAP. At the initial harvest, the number of vines was high, on further delay to harvest the number decreased due to weevil infestation but on further delay to harvest, the number of vines increased; this could have been as a result of regeneration of vines at the crowns. Type of planting materials significantly ($P<0.05$) differed on number of vines harvested during season I. Vine tips gave high number of vines at harvest, but were not significantly different from vine middle while sprouts gave the lowest vine number but they did not significantly differ from the vine middle. These results are at variance with Alcoy, (2007) who reported that vine tips and sprouts have higher number of vines as a result of high auxins that promote root formation resulting in high survival.

There was a positive and significant ($P<0.05$) correlation between yield of vines with the number of vines at harvest at 20% during season I. This implied that the higher the number of vines at harvest, the higher the total yields of vines (Stathers *et al.*, 2003).

Yield of vines negatively and significantly ($P<0.05$) correlated with vine damage at ($r=-0.243$) during season II (Table 4.4). This indicated that high vine damage led to lower vine yields. This is in line with studies by Stathers *et al.*, (2003) who found negative correlation between foliage weight and vine and crown damage.

4.1.2 Variety, in-ground storage and type of planting material effect on number of vines infested, percent weevil incidence, severity of weevil damage and weevil population density

Number of vines infested did not differ between the two varieties during season I (Table 4.1) but significantly ($P<0.05$) differed during season II (Table 4.2). SPK 004 significantly ($P<0.05$) had higher number of infested vines than SPK 013. Studies indicate that there is a consistence difference in susceptibility to *Cylas* among different varieties (Powell *et al.*, 2001; Ndolo *et al.*, 2001; Stathers *et al.*, 2003). This is attributed to SPK 004 having thin woody stems that could easily be infested (Degras, 2003). The number of infested vines were significantly ($P<0.05$) highest at 330 DAP during both seasons but did not differ from 210 DAP and 270 DAP and lowest at 150 DAP during season I. While during season II, 210 DAP significantly ($P<0.05$) had higher number of infested vines than 270 DAP (Table 4.1 &4.2). This is as a result of harvesting at the onset of long rains preceding dry season when infestation were high but at 270 DAP, this period was during peak of long rains and the weather was not favourable for the weevil thus low infestation (Appendix 2). The type of planting material did not have an effect on number of vines infested by sweetpotato weevils during season I but significantly ($P<0.05$) differed during season II. Vine middle was significantly ($P<0.05$) with the highest number of infested vines than vine tips and sprouts. The vine middle is woody and could easily be attacked while sprouts and vine tips have young vegetative parts that produce more latex thus reduced weevils damage (Stevenson *et al.*, 2009).

Variety SPK 004 had significantly ($P<0.05$) higher percent weevil incidence than SPK 013 during both seasons (Table 4.1 and 4.2). SPK 013 has thick stems and broad leaves which probably were less preferred by the weevils. Where as, SPK 004 has thin stems preferred by weevils (Degrs, 2003). Percent weevil incidence significantly ($P<0.05$) differed among different in-ground storage period during both seasons. The highest percent weevil incidence was recorded at 330 DAP which did not differ from 270 DAP while the lowest was significantly ($P<0.05$) at 150 DAP than other in-ground storage period while, at 210 DAP did not differ from 270 DAP during season I (Table 4.1). During season II, highest recorded weevil incidence was at 330 DAP with no significant difference from 210 DAP while 150 DAP significantly ($P<0.05$) had the lowest (Table 4.2). Vine middle significantly ($P<0.05$) had higher weevil incidence (49%) than vine tips and sprouts during season II (Table 4.2). There was also significant interaction effect among type of planting material by in-ground storage period on percent weevil incidence on vines. At 150 DAP, all types of planting materials had low percent weevil incidence which increased at a high rate up to 210 DAP, sprouts and vine middle decreased and then increased at 270 DAP until 330 DAP at high rate than vine tips. However, the vine tips increased at a lower rate up to 210 DAP then decreased at a lower rate to 270 DAP and then increased on further delay to harvest (Figure 4.3). The results show that with time weevils' percent incidence on different types of planting materials increase and decrease at different rates. Percent vine weevil incidence had a positive and significant correlation with crown damage ($r=0.579$) and (r=0.515) during season I and crown density (r=0.515) during season II (Table 4.3 and 4.4). The higher the number of infested vines the higher the crown damage and high crown weevil population.

Severity of damage by sweetpotato weevil on vines did not differ between the two varieties during both seasons. However, the highest severity of damage on vines was at 330 DAP but this was not significantly (P<0.05) different from 210 DAP and 270 DAP while the lowest severity of damage was recorded at 150 DAP during both seasons (Table4.1 and 4.2). Vine middle significantly (P<0.05) was severely damaged than vine tips and sprouts during season I (Table 4.1).The study agreed with studies by Kays *et al.*, 1985 and Data *et al.*, 1996 which indicated that, young vines produce more latex and tends to be less damaged.

Weevil density on vines significantly (P<0.05) differed between the two varieties. During season I and II, significantly (P<0.05) weevil density of 10 and 19 was recorded on SPK 004 compared with 2 and 3 on SPK 013 respectively (Table 4.1 and 4.2). SPK 004 was more preferred than SPK 013 as it had thin woody stems most preferred by weevils (Degras, 2003). Highest weevil density was at 330 DAP but did not significantly (P<0.05) differ from 270 DAP. While the lowest weevil density was recorded at 150 DAP which significantly (P<0.05) differed from 210 DAP (Table 4.1). This is in line with findings by Nedunchezhiyan *et al.*, (2010) which showed that vine weevil density increase with age. While during season II weevil density on vines was significantly (P<0.05) high at 330 DAP than 150 DAP, 210 DAP and 270 DAP which did not significantly (P<0.05) differ. Vine middle significantly (P<0.05) had high density than vine tips and sprouts during both seasons. The reason of higher populations in vine middle is that their stems are woody, preferred by weevils for oviposition and on egg hatching, weevil larvae easily tunnel through (Jannson *et al.*, 1990).

There was significant variety by in-ground storage period interaction on vine weevil density during both seasons. Weevil density on vines of SPK 004 increased the longer the crop delayed in-ground while SPK 013 maintained the same (Figure 4.1). This was in line with studies by Nedunchezhiyan *et al.* (2010) which indicated that weevil infestation in vines, increase with age of the crop. SPK 004 significantly ($P<0.05$) had higher weevil density which increased at a higher rate on delay to harvest while SPK 013 had low density which increased at a lower rate during the entire storage period (Figure 4.2). The weevil population density positively and significantly ($P<0.05$) correlated with infested number of vines at harvest ($r=0.497$) season I ($r=0.960$) season II and severity of vine damage ($r=0.408$) season I ($r=0.313$) season II (Table 4.3 and 4.4) respectively. The more the number of infested vines, the higher the vine damage and high vine weevil population.

Table 4.1 Effect of variety, in-ground storage period and type of planting material on yield and damage of sweetpotato vines and crowns by *Cylas spp* at Bukura agricultural college, Kakamega during season I (June, 2009 – May, 2010)

Factor	No at harvest10^3/ha	No Infested10^3/ha	% Weevil Incidence	severity of damage (score 1-5)	Weevil density on 5 infested vines	Yield at harvest (tons/ha)
Variety						
SPK 013	26.9 a	8.9 a	33.1 (5.1) b	1.4 (1.0) a	1.9 (1.6) b	35.0 a
SPK 004	24.9 a	11.5 a	46.2 (6.2) a	1.5 (1.5) a	10.5 (3.0) a	27.5 b
Lsd (0.05)	ns	ns	0.7	ns	0.3	5.3
Inground storage period						
150 DAP	24.7 a	0.8 b	3.2 (1.7) c	0.0 (1.4) b	1.1 (1.3) c	23.9 b
210 DAP	25.6 a	10.6 a	41.4 (6.1) b	1.2 (2.0) a	4.7 (2.2) b	35.0 a
270 DAP	27.5 a	13.9 a	50.5 (7.0) ab	1.5 (2.0) a	9.5 (2.9) a	32.1 a
330 DAP	25.7 a	15.4 a	60.0 (7.7) a	2.0 (2.0) a	12.3 (3.3) a	36.8 a
Lsd (0.05)	ns	5.1	1.0	0.1	0.4	7.5
Type of Planting material						
Sprouts	24.9 b	10.3 a	42.4 (5.8) a	0.3(1.1) b	5.7 (2.3) b	30.4 a
Vine tips	26.9 a	9.7 a	36.0 (5.4) a	0.3(1.1) b	6.5 (2.4) b	32.5 a
Vine Middle	25.8 ab	10.5 a	39.1 (5.6) a	1.5(1.4) a	8.7 (2.7) a	31.9 a
Lsd (0.05)	1.5	ns	ns	0.1	0.2	ns
CV%	12.6	19.6	21.8	14.3	24	25.3

ns = not significant

Means followed by similar letters are not significantly ($P<0.05$) different using LSD

Figures in parenthesis are means of transformed values

Table 4.2 Effect of variety, in-ground storage period and type of planting material on yield and damage of sweetpotato vines by *Cylas spp* at Bukura agricultural college, Kakamega during season II (September, 2009 – August, 2010)

Factor	No at harvest10^3/ha	No Infested10^3/ha	% Weevil Incidence	severity of damage (score 1-5)	Weevil density on 5 infested vines	Yield at harvest (tons/ha)
Variety						
SPK 013	25.2 a	7.3 b	29.0 (5.0) b	1.8 (1.6) a	2.5 (1.8) b	47.3 a
SPK 004	24.7 a	13.1 a	53.0 (7.0) a	2.8 (1.9) a	18.9 (4.0) a	37.9 b
Lsd (0.05)	ns	4.6	1.1	ns	0.2	8.6
Inground storage period						
150 DAP	25.6 ab	3.8 d	14.8 (3.5) c	1.9 (1.6) b	4.6 (2.4) b	33.1 b
210 DAP	23.5 b	12.2 b	52.0 (7.2) ab	2.3 (1.8) a	7.3 (2.5) b	46.5 a
270 DAP	23.8 b	9.0 c	37.8 (5.8) b	2.2 (1.8) a	10.4 (3.0) b	47.0 a
330 DAP	27.1 a	15.7 a	55.4 (7.6) a	2.7 (1.9) a	22.3 (4.0) a	43.8 a
Lsd (0.05)	2.3	2.6	1.5	0.1	0.8	11.1
Type of Planting material						
Sprouts	25.2 a	8.9 b	35.3 (5.6) b	2.0 (1.7) a	7.9 (2.5) b	44.1 a
Vine tips	25.1 a	9.7 b	38.6 (5.8) b	2.3 (1.8) a	7.0 (2.4) b	42.8 a
Vine Middle	24.6 a	12.0 a	48.8 (6.7) a	2.5 (1.8) a	18.6 (3.8) a	40.9 a
Lsd (0.05)	ns	1.9	0.8	ns	0.4	ns
CV%	13.8	32.1	34	15.3	42.9	23.9

ns = not significant

Means followed by similar letters are not significantly ($P<0.05$) different using LSD

Figures in parenthesis are means of transformed values

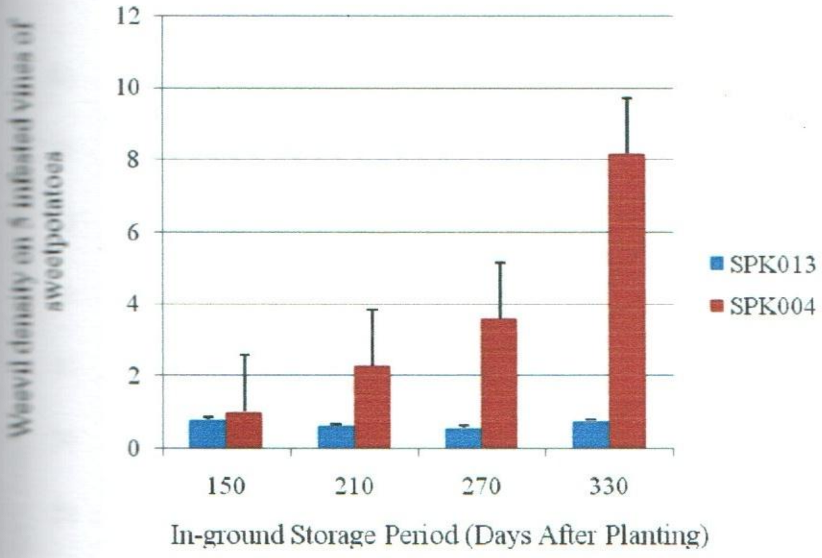

Figure 4. 1 Effect of Variety x In-ground storage period on weevil density of vines during season I (September, 2009 – August, 2010)

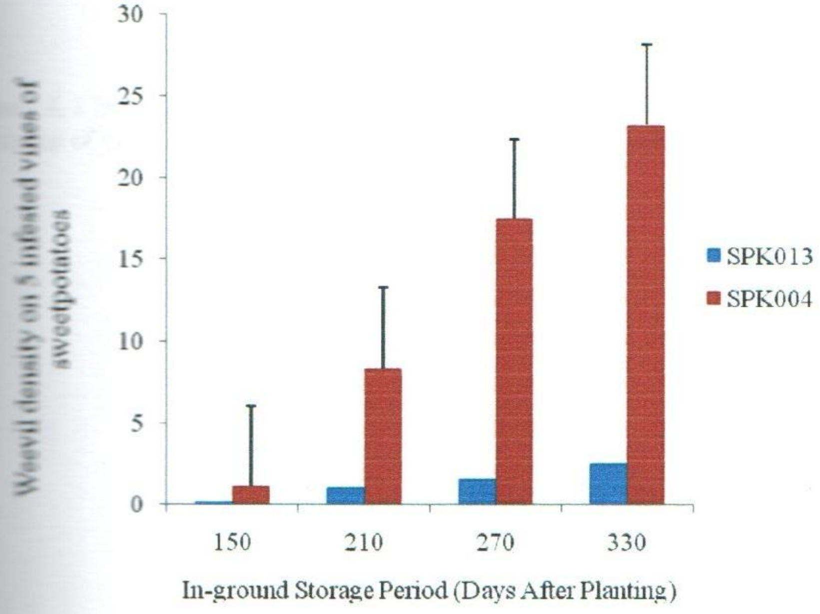

Figure 4.2 Effect of Variety x In-ground storage period on weevil density of vines during season II (September, 2009 – August, 2010)

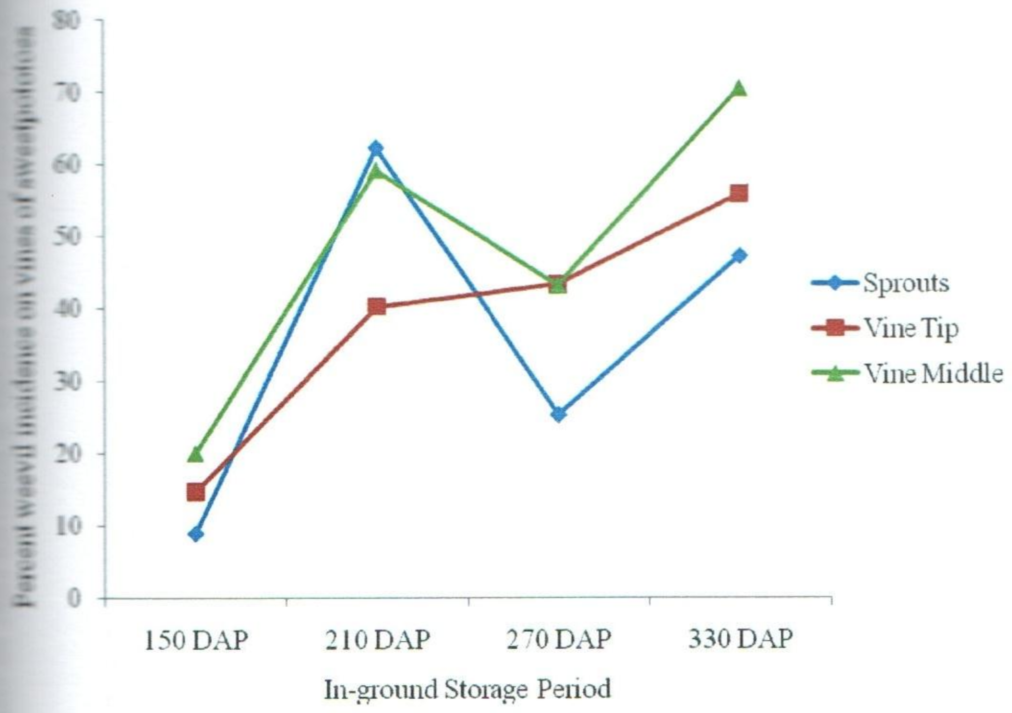

Figure 4. 3 Effect of Planting Material x In-ground storage period on percent weevil incidence of vines during season II (September, 2009 – August, 2010)

Table 4.3 Correlation coefficient among yield and infestation parameters on vines harvested at Bukura agricultural college, Kakamega during season I (June, 2009 – May, 2010)

	Vine number.	Infested number	Vine damage	% incidence	Vine density	Crown Severity	Crown density	Yield Vines
Vine number	1							
Infested number	0.212	1						
Vine damage	0.037	0.340*	1					
% incidence	-0.006	0.966*	0.579	1				
Vine density	-0.031	0.497*	0.408*	0.515*	1			
Crown damage	0.201	0.600*	0.742*	0.579*	0.408*	1		
Crown density	0.172	0.604*	0.268*	0.515*	0.538*	0.407*	1	
Yield of vines	0.200*	0.029	0.025	0.021*	-0.050	0.237	-0.051	1

* Significant P<0.05

Table 4.4 Correlation coefficient among yield and infestation parameters on vines harvested at Bukura agricultural college, Kakamega during season II (September, 2009 – August, 2010)

	Vine number	Infested number	Vine damage	Vine incidence	Vine density	Crown damage	Crown density	Yield Vines
Vine number	1							
Infested number	0.209	1						
Vine damage	0.201	0.600*	1					
Vine incidence	0.144	-0.046*	-0.098*	1				
Vine density	-0.030	0.960*	0.313*	-0.066	1			
Crown damage	0.172	0.604*	0.268*	-0.121*	0.538*	1		
Crown density	-0.031	0.496*	0.408*	0.515*	1*	0.408	1	
Yield vines	-0.037	-0.051*	-0.243*	0.130*	-0.057*	-0.239*	-0.239	1

*Significant P<0.05

4.2 Effect of variety, in-ground storage period and type of planting material on weevil infestation and yields of sweetpotato storage roots

4.2.1 Variety, in-ground storage period and type of planting material effect on number and yield of storage roots of sweetpotatoes

Variety, in-ground storage period and type of planting material significantly ($P<0.05$) had an influence on infestation and yield of storage roots of sweetpotatoes harvested during season I and season II at Bukura (Table 4.5 and 4.6). Number of marketable storage roots did not differ between the two varieties during both seasons. However, 330 DAP recorded highest number of storage roots during both seasons but did not differ from 270 DAP during season I and from 270 DAP and 210 DAP during season II. The lowest number was significantly ($P<0.05$) at 150 DAP during both seasons (Table 4.5 and 4.6). This indicated that delay to harvest had an increase in number of marketable storage roots. Sprouts significantly ($P<0.05$) had reduced numbers of marketable storage roots than vine tips and vine middle during season I but did not differ from the vine middle during season II. Vine tips significantly ($P<0.05$) had high number of storage roots with no significant difference to vine middle during both seasons (Table 4.5 and 4.6).

Number of unmarketable storage roots significantly ($P<0.05$) differed between the two varieties during both seasons (Table 4.5 and 4.6). SPK 004 significantly ($P<0.05$) had the highest number of unmarketable storage roots during both seasons. During season II, 210 DAP significantly ($P<0.05$) had the highest number of unmarketable with no significant difference from 330 DAP while 270 DAP and 150 DAP significantly ($P<0.05$) had the lowest but did not differ from 330 DAP. At 210 DAP; harvest was done at onset of long rains (Appendix 2) while 270 DAP there was high rainfall (wet conditions) not conducive for root enlargement (O`Hair, 1991).

Total number of storage roots significantly ($P<0.05$) differed between the two varieties. SPK 004 significantly ($P<0.05$) had higher total number of storage roots than SPK 013 during both seasons. The highest total number of storage roots was recorded at 270 DAP but did not differ from 210 DAP and 330 DAP during season I (Table 4.5) while 150 DAP had lowest number during both seasons. However, during season II 330 DAP significantly ($P<0.05$) had the highest total number of storage roots than the others but 210 DAP did not significantly ($P<0.05$) differ from 270 DAP. Sprouts had lower total number of storage roots than the vine tip and vine middle during both seasons (Table 4.5 and 4.6).

Yield of marketable storage roots significantly ($P<0.05$) differed between the two varieties during season I SPK 013 significantly ($P<0.05$) had higher yields of marketable storage roots than SPK 004. Despite high rainfall distribution and high yield of vines during season II, the yield of storage roots did not differ. This contradicts studies by Firon *et al*, (2009) which indicated high yields of vines, better partitioning of assimilates as storage root growth is linked to canopy. Yield of marketable roots was significantly ($P<0.05$) higher at 330 DAP with no significant difference from 210 DAP and 270 DAP during both seasons. These contradict studies by Anioke and Ogbahu (2003) which showed increase in market yield with increase in age. During season II vine tips had significantly ($P<0.05$) high marketable yields of storage roots with no significant difference from vine middle while sprouts significantly ($P<0.05$) giving low yields. This does not concur to studies by Firon *et al*. (2009) which indicated that mature planting stalk develop lignification that restrict root development leading to low yields.

Yield of marketable infested storage root did not differ between the two varieties and among types of planting material during both seasons. However, at 330 DAP yields of marketable infested storage roots were significantly ($P<0.05$) higher with no significant difference from 270 DAP while 150 DAP and 210 DAP had the lowest during season II (Table 4.6).

Yield of unmarketable storage yield differed significantly ($P<0.05$) between varieties during season I and among in-ground storage period season II. There was no significant difference among planting materials in both seasons. Yield of unmarketable storage roots was significantly ($P<0.05$) high on SPK 004 during season II. This was attributed to high number of unmarketable storage root 50% higher than SPK 013. In-ground storage period of 210 DAP had higher yield of unmarketable storage root with no significant difference on further delay to harvest.

Total yield of storage roots significantly ($P<0.05$) differed between the two varieties during season I but in-ground storage period and type of planting material significantly ($P<0.05$) differed during both seasons. SPK 013 significantly ($P<0.05$) produced 24% more storage root yields than SPK 004. This was as a result of SPK 013 having large and heavier storage roots than SPK 004 (Table 4.5).This was in line with the study by Ndolo *et al.*, (2001) which showed that SPK 013 out yield SPK 004.The yields of SPK 004 was low as a result of high number of infested marketable storage roots where 50% of marketable were infested and a high proportion of small storage roots which had light weight (Table 4.5). Storage at 330 DAP significantly ($P<0.05$) recorded higher yields with no significant difference from 210 DAP and 270 DAP while 150 DAP significantly ($P<0.05$) had lower yields during both seasons. Vine tips significantly ($P<0.05$) had high total yield of storage roots than vine middle and sprouts during season I which was not significantly ($P<0.05$) different from vine middle during season II (Table 4.5 and 4.6) while sprouts significantly ($P<0.05$) had lower yields than vine middle and vine tips during both seasons. The results were in agreement with studies by Alcoy, (2007) which indicated that vine tips give higher yields than basal cuttings.

Storage root yield had positive and significant correlation with total and marketable number of storage roots ($r=0.44$;$r=0.43$ and $r=0.68$;$r=0.59$) during both seasons respectively (Table 4.9 and 4.10) and high positive significant correlation with weight of marketable storage roots ($r=0.99$ and $r=0.98$).These characteristics contributed to variation in yields of the sweetpotato as shown in studies by (Alcoy, 2007). The high total yields of storage roots were as a result of more heavy marketable roots which weighed high during both seasons.

Table 4.5 Effect of variety, type of planting material and in-ground storage period on number and yield of storage roots of sweetpotatoes at Bukura Agricultural College, Kakamega during season I (June, 2009 – May, 2010)

Factor	Number of Storage Roots (10^3/ ha)			Yield of Storage Roots (tons/ha)			
	marketable	unmarketable	Total	marketable	marketable infested	unmarketable	Total
Variety							
SPK 013	37.8 a	20.1 (4.5) b	57.9 b	20.1 (4.3) a	2.8 (1.1) a	1.5 (1.6) a	21.6 (4.5) a
SPK 004	41.8 a	36.1 (6.0) a	77.9 a	10.8 (3.3) b	0.8 (0.3) a	2.5 (1.8) a	11.3 (3.7) b
Lsd (0.05)	ns	1.4	10.1	0.6	ns	ns	0.5
In-ground storage period							
150 DAP	22.6 c	27.3 (5.2) a	49.9 c	6.8 (2.7) b	1.7 (1.5) a	1.5 (1.6) a	8.3 (2.9) b
210 DAP	39.9 b	22.0 (4.7) a	61.9 b	15.4 (3.8) a	2.1 (1.6) a	1.3 (1.5) a	16.8 (4.0) a
270 DAP	46.2 ab	35.5 (5.7) a	81.7 a	17.7 (4.2) a	1.3 (1.4) a	3.1 (2.0) a	20.8 (4.6) a
330 DAP	50.6 a	29.0 (5.3) a	79.6 a	21.8 (4.6) a	2.0 (1.6) a	2.2 (1.7) a	23.0 (4.8) a
Lsd (0.05)	8.8	ns	7.7	0.8	ns	ns	0.8
Type of Planting material							
Sprouts	31.9 b	27.4 (5.1) a	59.3 b	12.8 (3.5) a	1.7 (1.5) a	2.0 (1.7) a	14.8 (3.8) b
Vine tips	45.5 a	28.3 (5.3) a	73.8 a	18.5 (4.2) a	1.9 (1.5) a	2.0 (1.7) a	20.5 (4.4) a
Vine Middle	42.1 a	29.7 (5.4) a	71.8 a	14.9 (3.8) a	1.7 (1.5) a	2.0 (1.7) a	16.9 (4.0) b
Lsd (0.05)	7.7	ns	4.1	ns	ns	ns	0.3
CV (%)	31.7	40.1	25.5	17..5	41.4	12..9	15..9

ns - not significant

Means followed by similar letters are not significantly ($P<0.05$) different using LSD

Figures in parenthesis are means of the transformed values

Table 4.6 Effect of variety, type of planting material and in-ground storage period on number and yield of storage roots of sweetpotatoes at Bukura Agricultural College, Kakamega during season II (September, 2009 – August 2010)

Factor	Number of Storage Roots (10^3/ ha)			Yield of Storage Roots (tons/ha)			
	marketable	unmarketable	Total	marketable	marketable infested	unmarketable	Total
Variety							
SPK 013	27.1 (5.2) a	10.4 (3.2) b	37.5 b	16.5 (4.0) a	0.2(0.2) a	2.0 (2.2) a	18.5 (4.3) a
SPK 004	41.7 (6.3) a	31.2 (5.5) a	72.9 a	11.7 (3.5) a	0.4(0.3) a	3.0 (2.1) a	14.8 (3.9) a
Lsd (0.05)	ns	1.4	21.7	ns	ns	ns	ns
In-ground storage period							
150 DAP	24.2 (4.9) b	16.7 (3.9) b	40.9 c	9.3 (3.1) b	0.0(0.0) b	1.5 (2.0) a	10.8 (3.4) b
210 DAP	30.3 (5.4) b	25.8 (4.9) a	56.1 b	14.7 (3.8) a	0.2(0.1) b	3.0 (2.2) a	17.7 (4.2) a
270 DAP	41.2 (6.3) a	16.5 (3.9) b	57.7 b	17.5 (4.2) a	0.5(0.5) a	2.7 (2.3) a	20.2 (4.5) a
330 DAP	41.8 (6.3) a	24.3 (4.7) ab	66.1 a	15.0 (3.9) a	0.5(0.5) a	2.7 (2.2) a	17.7 (4.2) a
Lsd (0.05)	0.8	0.9	6.5	0.6	0.2	ns	0.7
Type of Planting material							
Sprouts	28.8 (5.2) b	17.3 (4.0) a	46.1 b	11.7 (3.4) b	0.2(0.2) a	2.2 (2.1) a	13.9 (3.7) b
Vine tips	40.0 (6.2) a	21.7 (4.4) a	61.7 a	16.3 (4.1) a	0.3(0.2) a	2.4 (2.2) a	18.7 (4.4) a
Vine Middle	34.8 (5.8) ab	23.5 (4.7)a	58.3 a	14.4 (3.8) a	0.4(0.4) a	2.8 (2.2) a	17.2 (4.1) a
Lsd (0.05)	0.7	ns	4.2	0.4	ns	ns	0.3
CV (%)	21.5	17.7	31.9	18.3	34.1	7.3	16.3

ns - not significant

Means followed by similar letters are not significantly ($P<0.05$) different using LSD

Figures in parenthesis are means of the transformed values

4.2.2 Effect of variety, in-ground storage period and type of planting material on percent weevil incidence, weevil density and severity of damage on sweetpotato storage roots

Number of marketable storage roots infested by the weevils differed significantly (P<0.05) between the two varieties during both seasons (Table 4.7 and 4.8). SPK 004 significantly (P<0.05) had high number of infested marketable storage roots during both seasons with highest infestation during season I where 50% of harvested marketable storage roots were infested (Table 4.7) but only 25% during season II (Table 4.8). This concurs with results by Ndolo *et al.*, (2001) who reported that SPK 004 has high infestation than SPK 013. Number of infested marketable storage root also significantly (P<0.05) showed an interaction effect on variety by type of planting material. SPK 004 significantly (P<0.05) had higher number of infested on vine middle with the same infestation on vine tips and sprouts during both seasons (Figure 4.6). However, SPK 013 maintained same rate of number infested on all types of planting material used during both seasons. This showed that SPK 004 has lower and similar rate of number infested on vine tips and sprouts but high rate on vine middle while SPK 013 had the same rate on all types of planting material.

There was significant (P<0.05) variety by in-ground storage period interaction effect on number of marketable infested storage roots during both seasons. Both varieties were infested and infested marketable storage roots increased with delay to harvest. SPK 004 increased at a higher rate during both seasons than SPK 013. SPK 004 rate of increase was high up to 210 DAP then increased at a reducing rate at 270 DAP and finally decreased at 330 DAP during season I than SPK 013 (Figure 4.4). During season II, the rate of increase for SPK 004 was high the entire storage period while SPK013 rate of number infested increased at a lower rate (Figure 4.4). This indicated that the rate of increase in number of storage roots infested depended on delay to harvest and type of variety of sweetpotato.

In-ground storage period during season I significantly (P<0.05) recorded an increasing number of infested marketable storage roots with delay to harvest (Table 4.7). Storage period at 330 DAP significantly (P<0.05) had higher number of infested roots but did not differ from 270 DAP while 150 DAP had the lowest during season I. However, during season II 330 DAP significantly (P<0.05) had high infested number which did not differ from 270 DAP whereas 150 DAP had the lowest but did not differ from 210 DAP and 270 DAP (Table 4.8). These results indicate the longer the crop harvest delay, weevil infestation increase.

Vine tips significantly (P<0.05) had the lowest infested number of marketable storage roots than sprouts and vine middle during season I (Table 4.7). The results concurs with studies by Tewe *et al.,(* 2003), Alcoy, (2007) and Novak, (2007) who reported low weevil infestation on young portions of the vines. However, during season II there was no significant difference from sprouts and vine tips but vine middle had the highest infested number of marketable storage roots during both seasons (Table 4.8). There was a significant (P<0.05) variety by planting material interaction on infested number of marketable roots during both season. Vine middle of SPK 004 was significantly (P<0.05) infested than sprout and vine tip during both seasons while SPK 013 all planting material had similar infested number every season (Figure 4.5). There was significant type of planting material by in-ground storage period interaction effect on number of marketable infested storage roots during season I (Figure 4.6). At 150 DAP, all types of planting materials had lower infested number, vine middle and sprouts increased at an increasing rate up to 210 DAP then increased with a decreasing rate until final harvest. However, the vine tips maintained the same rate of increase during the entire period.

Table 4.7 and 4.8 showed that the percent weevil incidence in storage roots was significantly (P<0.05) higher on SPK 004 than SPK 013 during both seasons. Percent weevil incidence was highest during season I. During season I, there was significant (P<0.05) percent weevil incidence among in-ground storage period which increased with delay to harvest of 330 DAP recording the highest. This study was in line with Nedunchezhiyan *et al.*, 2010 and O'hair, 1991 findings which showed weevil infestation increase with age of the crop. However, during season II, percent weevil incidence was high at 330 DAP with no significant difference from 270 DAP (Table 4.8).

There was significant variety by in-ground storage period interaction effect on weevil incidence during both seasons. SPK 004 significantly ($P<0.05$) had high incidence which increased gradually with delay to harvest. Whereas, SPK 013 initially had no increase on percent weevil damage up to 270 DAP then increased at a very low rate (Figure 4.7). Percent weevil incidence on vine tips was significantly ($P<0.05$) lower than vine middle and sprouts during both seasons. Vine middle significantly ($P<0.05$) had the highest percent weevil incidence during season I but did not significantly ($P<0.05$) differ from sprouts during season II (Table 4.8). There was a significant ($P<0.05$) interaction between variety by type of planting material significantly ($P<0.05$) interaction where SPK 013 had low incidence on all types of planting materials with same percent weevil incidence on vine tips and vine middle but had very low percent incidence on sprouts. SPK 004 had higher weevil incidence on vine middle and sprouts but low on vine tips (Figure 4.8).

There was a positive significant $P<0.05$ correlation between percent weevil incidence and infested storage root number ($r=0.94$; $r=0.85$), severity of damage ($r=0.67$; $r=0.89$), weevil density ($r=0.90$; $r=0.62$) during season I and II (Table 4.9 and 4.10). However, percent weevil incidence had significantly ($P<0.05$) positive correlation with marketable root weight ($r=0.24$) season I and significantly ($P<0.05$) negative correlation ($r=-0.26$) indicating that there was a higher percent weevil incidence for lower marketable storage root weight and vice versa during season II (Table 4.10). This indicated that during season I damage was superficial and never affected weight of marketable storage roots as during season II.

SPK 004 significantly ($P<0.05$) had high weevil density than SPK 013. The density was highest during season I and low during season II (Table 4.7 and 4.8). This was because the variety was shallow rooted, thin stemmed and orange fleshed thus easily infested with weevils. A study on sweetpotato weevil resistance conducted at Asian Vegetable Research Development Center (AVDC), IITA and CIP indicated the same (Degras, 2003).During both seasons, weevil density significantly ($P<0.05$) increased with delay to harvest [illegible] DAP significantly ($P<0.05$) recorded the highest. However, during season

II weevil density at 150 DAP did not differ from 210 DAP. The experiment also showed significant (P<0.05) variety by in-ground storage period interaction effect on weevil density during both seasons. SPK 004 weevil densities increased to 210 DAP then increased at a decreasing rate and then increased at a high rate while SPK 013 maintained low weevil density (Figure 4.9). However, during season II SPK 004 increased at an increasing rate throughout the entire storage period but SPK 013 was low initially but increased at 270 DAP and decreased at 330 DAP (Figure 4.10).

Vine middle significantly (P<0.05) had higher weevil density than vine tips and sprouts during both seasons. However, sprouts had lowest weevil density during season II but did not differ from vine tips during season I (Table 4.8). Sweetpotato storage roots showed significant (P<0.05) variety by type of planting material interaction effect on weevil density during both seasons. SPK 004 showed a high density on vine middle but lower and same rate on sprouts and vine tips during season I (Figure 4.11) while during season II, vine middle had the highest density followed by vine tips and sprouts had the lowest. There was significant interaction effect on planting material by in-ground storage period during both seasons. All types of planting material increased up to 210 DAP, vine tips did not show any increase at 270 DAP while the others increased at a decreasing rate to 270 DAP but sprouts later decreased while the vine tips and vine middle increased at a higher rate during season I (Figure 4.12). However, during season II all types of planting materials showed low density up to 210 DAP vine tips and sprouts density increased at the same rate while the vine middle had a high rate at 270 DAP and later vine tips and vine middle decreased as sprouts increased(Figure 4.13).

Weevil density significantly (P<0.05) and positively correlated with total number of storage roots (r=0.53; r=0.58), number of infested storage roots (r=0.94; r=0.88) and severity root damage (r=0.73; r=0.69) during both seasons (Table 4.9 and 4.10). The more the infested roots and severe the infestation the higher the weevil population densities in the storage roots.

Severity of damage by sweetpotato weevil was significantly (P<0.05) higher on SPK 004 during both seasons an indication that it is more preferred than

SPK 013. There was significantly (P<0.05) higher severity of damage at 330 DAP and lowest severity at 150 DAP during season I (Table 4.7). This showed that delay to harvest result in increased damage especially during period of little rainfall while during season II highest severity was at 330 DAP but did not differ with 270 DAP (Table 4.8). There was significant (P<0.05) variety by in-ground storage period interaction effect on severity of damage on roots during season I. All varieties had low damage up to 210 DAP then damage increased on both varieties with SPK 013 having lower increase than SPK 004 (Figure 4.14). Vine middle was significantly (P<0.05) damaged more than vine tips and sprouts during both seasons. There was also significantly (P<0.05) interaction effect between planting material by in-ground storage period on severity of damage where all planting materials had low damage up to 210 DAP then increased at an increasing rate sprouts increased at lower rate at 270 DAP than vine tips and vine middle (Figure 4.15).

Table 4.7 Effect of variety, in-ground storage period and type of planting material on yield and damage of sweetpotato storage roots by Cylas spp at Bukura agricultural college, Kakamega during season I (June, 2009 – May, 2010)

Factor	No marketable(10^3)/ha	No marketable infested(10^3)/ha	% Weevil Incidence	Severity of damage (score 1-5)	Weevil density on 5 infested roots	Yield at harvest (tons/ha)
Variety						
SPK 013	37.8 a	1.3 b	3.4 b	1.4 b	0.7 b	21.6 (4.5) a
SPK 004	41.8 a	20.5 a	49.0 a	2.4 a	25.2 a	13.6 (3.7) b
Lsd (0.05)	6.3	1.8	8.6	0.4	2.2	0.5
In-ground storage period						
150 DAP	22.6 c	1.0 d	4.4 d	1.0 c	1.0 d	08.3 (2.9) b
210 DAP	39.9 b	6.9 c	17.3 c	1.0 c	12.4 c	16.8 (4.0) a
270 DAP	46.2 ab	14.4 b	31.2 b	2.1 b	15.3 b	20.8 (4.6) a
330 DAP	50.6 a	21.1 a	41.7 a	3.7 a	23.0 a	23.9 (4.8) a
Lsd (0.05)	8.8	2.6	4.8	0.2	2.2	0.8
Type of Planting material						
Sprouts	31.9 b	10.0 b	31.3 b	1.8 b	11.1 b	14.8 (3.8) b
Vine tips	45.5 a	7.9 b	17.4 c	1.9 b	11.6 b	20.5 (4.4) a
Vine Middle	42.1 a	14.7 a	35.0 a	2.1 a	16.0 a	16.9 (4.0) b
Lsd (0.05)	7.7	2.2	2.6	0.1	1.8	0.3
CV%	31.7	32.2	26.4	11.3	23.1	15.9

Means followed by similar letters are not significantly ($P<0.05$) different using LSD

ns = not significant

Figures in parenthesis are means of the original values

Table 4.8 Effect of variety, in-ground storage period and type of planting material on yield and damage of sweetpotato storage roots by *Cylas spp* at Bukura agricultural college, Kakamega during season II (September, 2009 – August, 2010)

Factor	No marketable (10^3)/ha	No marketable infested (10^3)/ha	% Weevil Incidence	severity of damage (score 1-5)	Weevil density on 5 infested roots	Yield at harvest (tons/ha)
Variety						
SPK 013	27.1 (5.2) a	0.6 (1.2) b	2.2 (1.5) b	1.7 (1.6) b	0.2 b	18.4 (4.3) a
SPK 004	41.7 (6.3) a	9.8 (3.0) a	13.4 (3.4) a	2.5 (1.8) a	11.2 a	14.8 (3.9) a
Lsd (0.05)	ns	1.2	0.5	ns	2.7	ns
In-ground storage period						
150 DAP	24.2 (4.9) b	1.8 (1.4) b	1.2 (1.3) c	1.0 (1.4) b	0.2 c	10.8 (3.4) b
210 DAP	30.3 (5.4) b	3.5 (1.9) b	5.7 (2.3) b	1.5 (1.4) b	1.9 c	17.7 (4.2) a
270 DAP	41.2 (6.3) a	6.7 (2.4) ab	9.9 (2.8) ab	3.5 (2.0) a	8.1 b	20.2 (4.5) a
330 DAP	41.8 (6.3) a	8.9 (2.8) a	14.4 (3.4) a	2.5 (1.8) a	12.6 a	17.7 (4.2) a
Lsd (0.05)	0.8	0.5	0.7	0.2	3.8	0.7
Type of Planting material						
Sprouts	28.8 (5.2) b	4.9 (1.9) b	8.0 (2.6) a	1.8 (1.6) b	3.2 c	13.9 (3.7) b
Vine tips	40.0 (6.2) a	4.0 (1.9) b	5.7 (2.2) b	1.8 (1.6) b	5.0 b	18.7 (4.4) a
Vine Middle	34.8 (5.8) ab	6.7 (2.5) a	9.7 (2.8) a	2.8 (1.8) a	8.9 a	17.2 (4.1) a
Lsd (0.05)	0.7	0.3	0.3	0.1	1.5	0.3
CV%	21.5	21.9	35.7	24.4	31.8	16.3

Means followed by similar letters are not significantly (P<0.05) different using LSD

ns = not significant

Figures in parenthesis are means of the transformed values

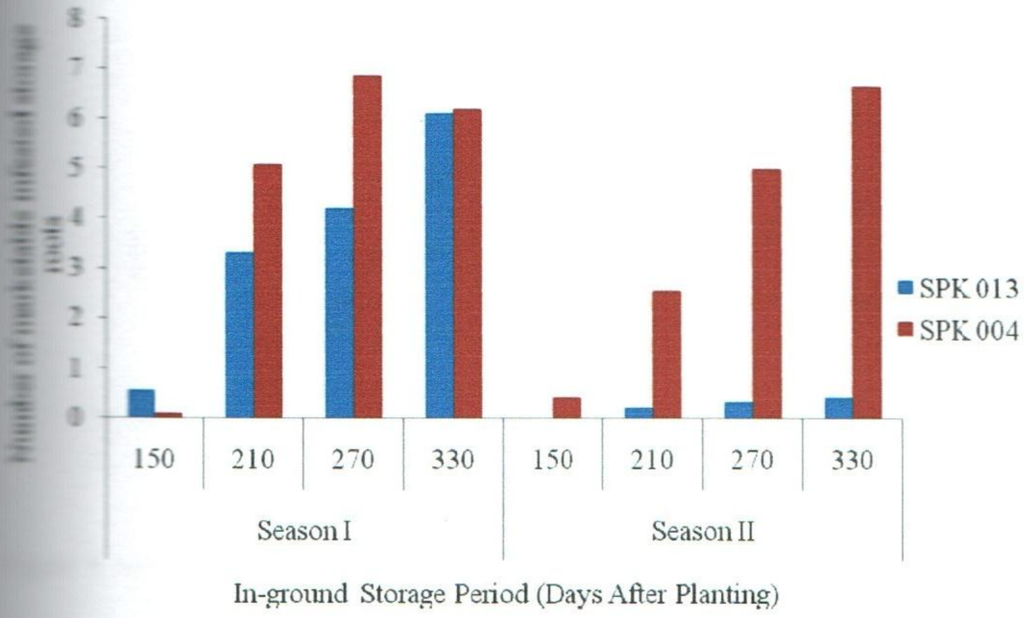

Figure 4.4 Effect of Variety x In-ground storage period on number of marketable infested storage roots during season I (June, 2009 – May, 2010) and II (September, 2009 – August, 2010)

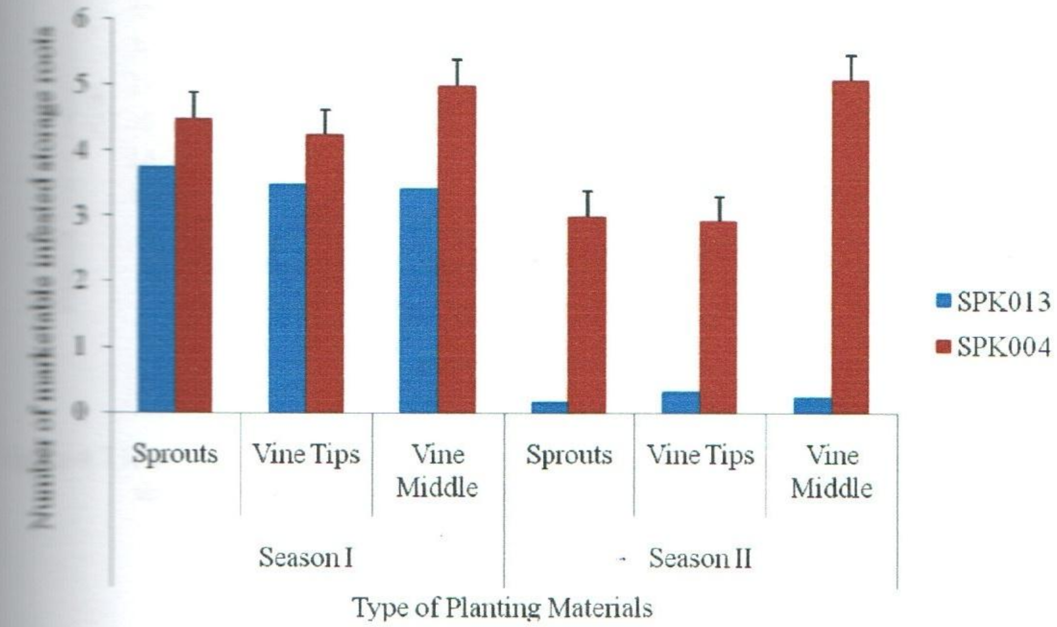

Figure 4. 5 Effect of Variety x Planting Material on number of marketable infested storage roots during season I (June, 2009 – May, 2010) and II (September, 2009 – August, 2010)

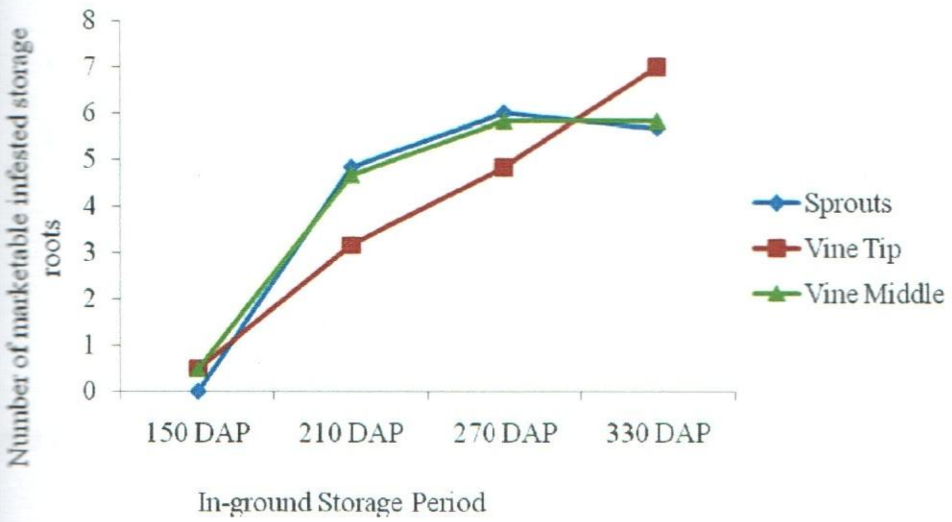

Figure 4. 6 Effect of Planting Material x In-ground storage period on number of marketable infested storage roots during season I (June, 2009 – May, 2010)

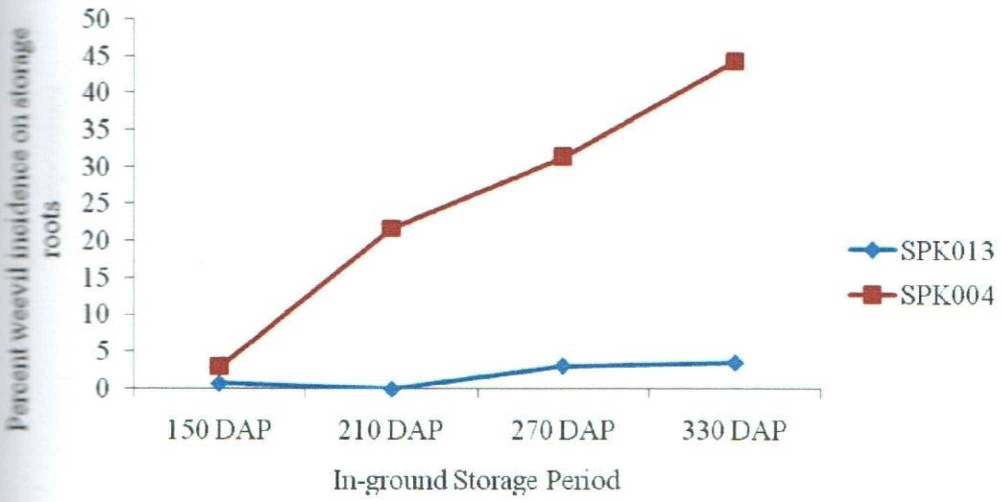

Figure 4.7 Effect of Variety x In-ground storage period on percent weevil incidence of storage roots during season I (June, 2009 – May, 2010)

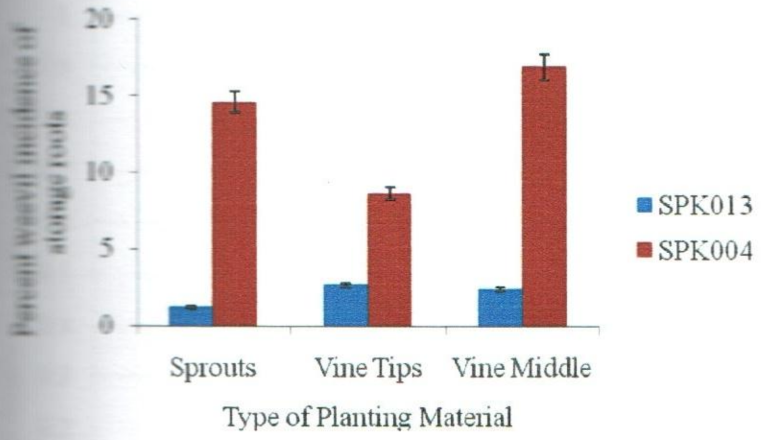

Figure 4.8 Effect of Variety x Planting Material on percent weevil incidence of storage roots during season II (September, 2009 – August, 2010)

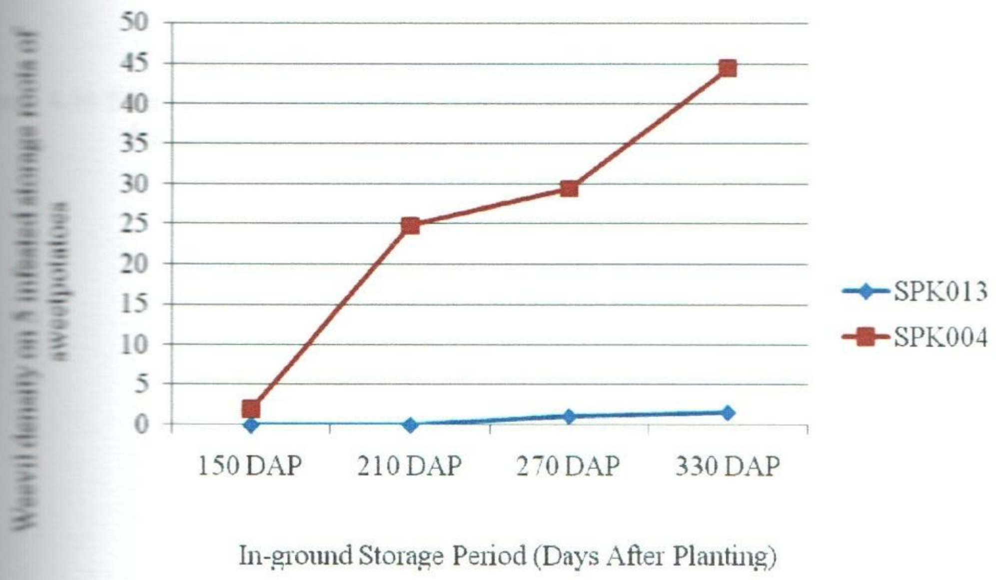

Figure 4.9 Effect of Variety x In-ground storage period on weevil density of storage roots during season I (June, 2009 – May, 2010)

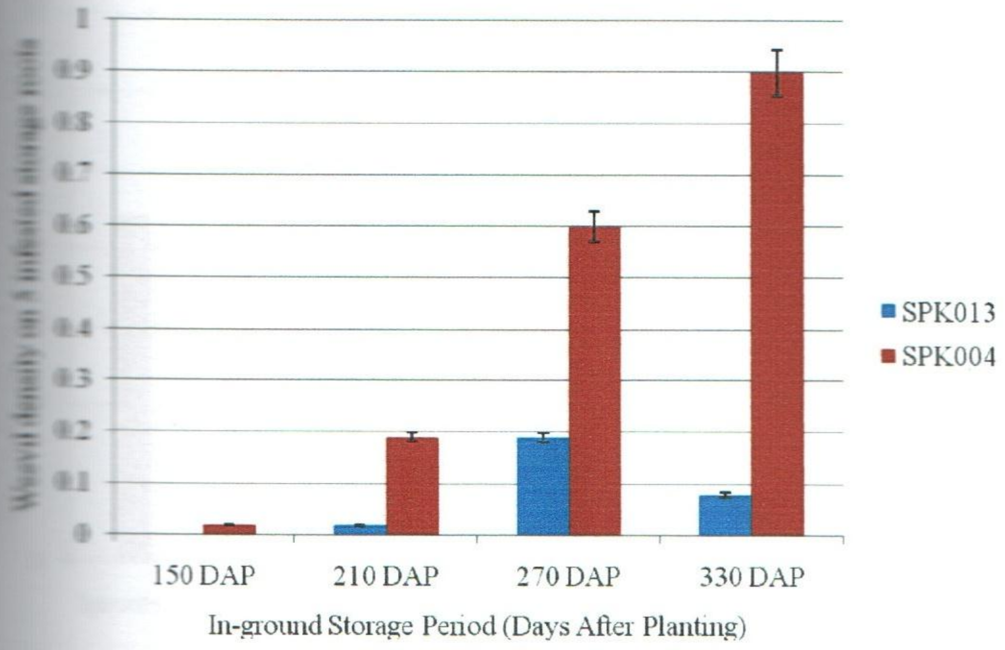

Figure 4.10 Effect of Variety x In-ground storage period on weevil density of storage roots during Season II (September, 2009 – August, 2010)

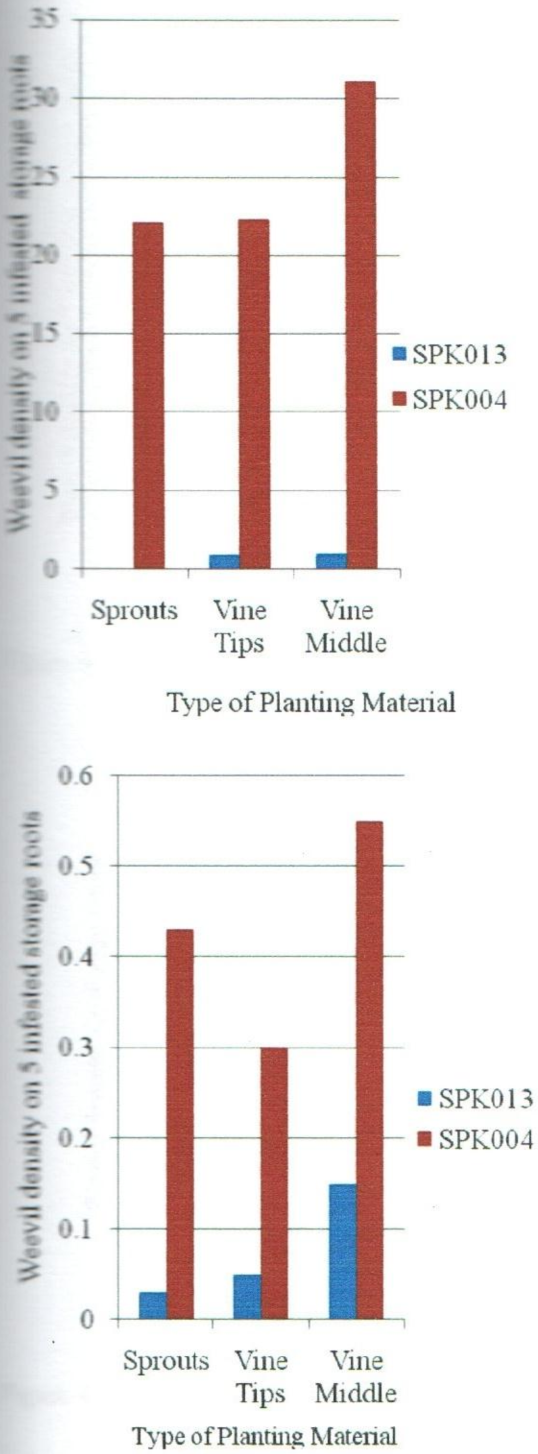

Figure 4.11 Effect of Variety x Planting Material on weevil density of storage roots during season I (June, 2009 – May, 2010) and II (September, 2009 – August, 2010)

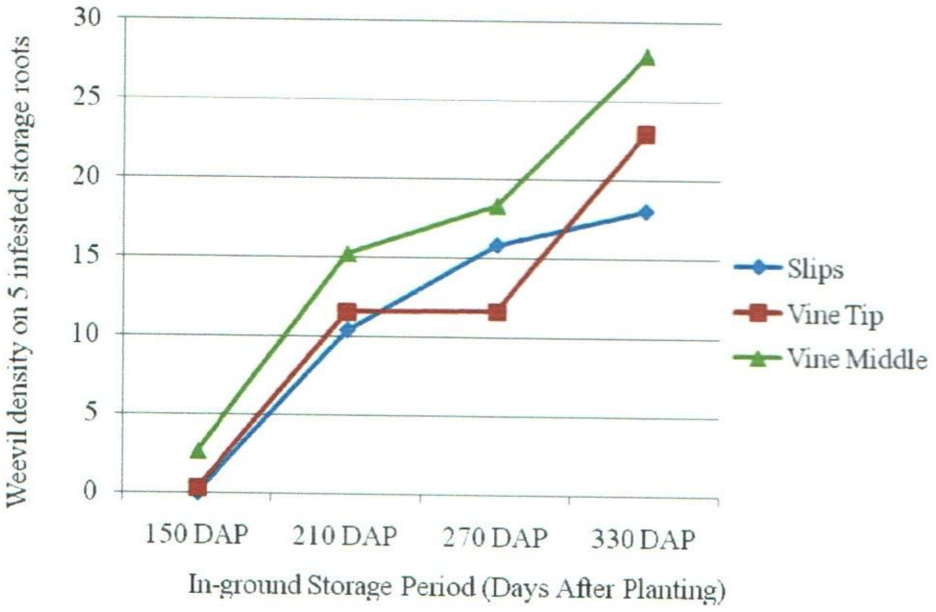

Figure 4. 12 Effect of Planting Material x In-ground storage period on weevil density of storage roots during season I (June, 2009 – May, 2010)

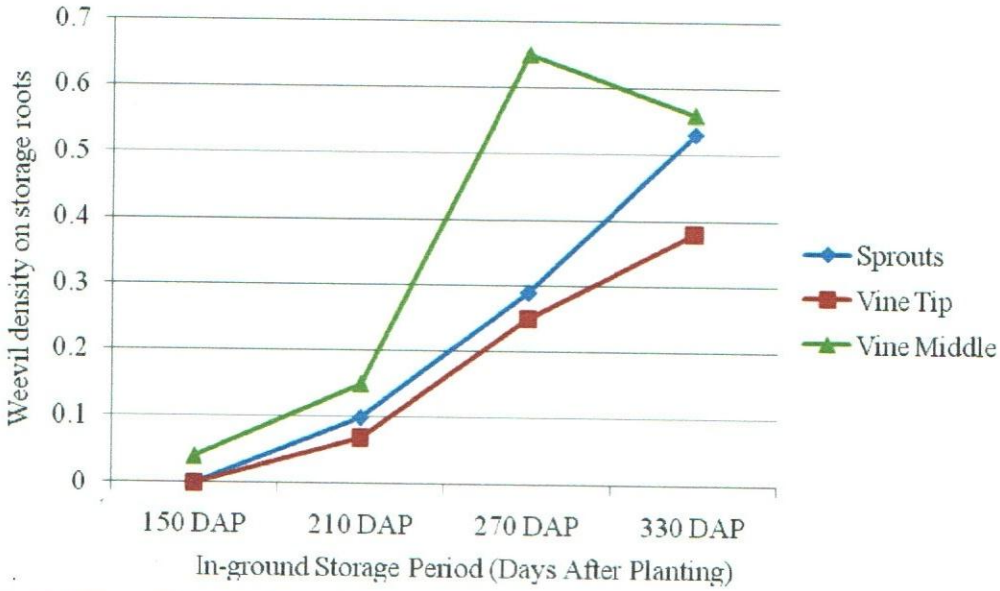

Figure 4. 13 Effect of Planting Material x In-ground storage period on weevil density of storage roots during season II (September, 2009 – August, 2010)

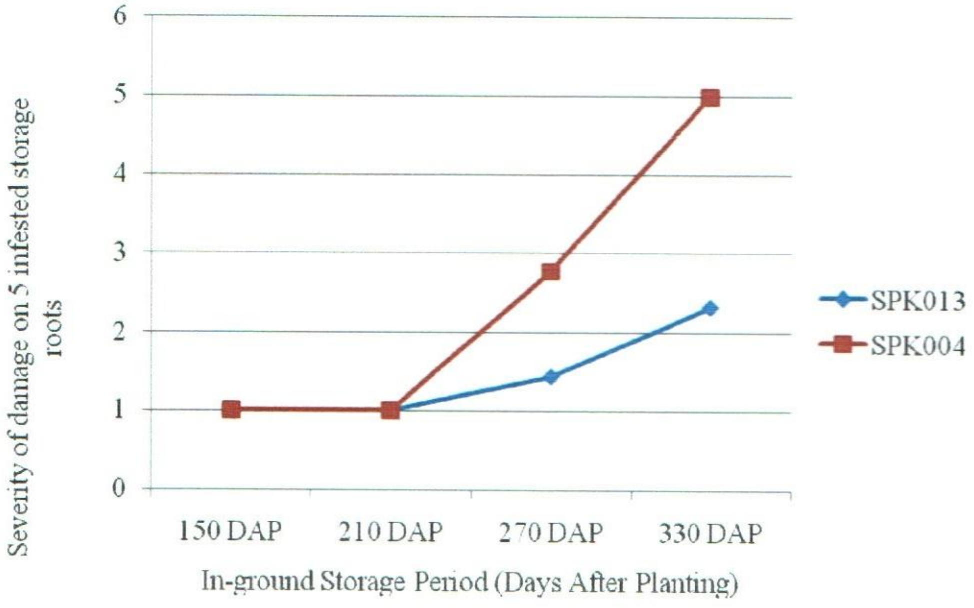

Figure 4. 14 Effect of Variety x In-ground storage period on severity of damage of storage roots during season I(June, 2009 – May, 2010)

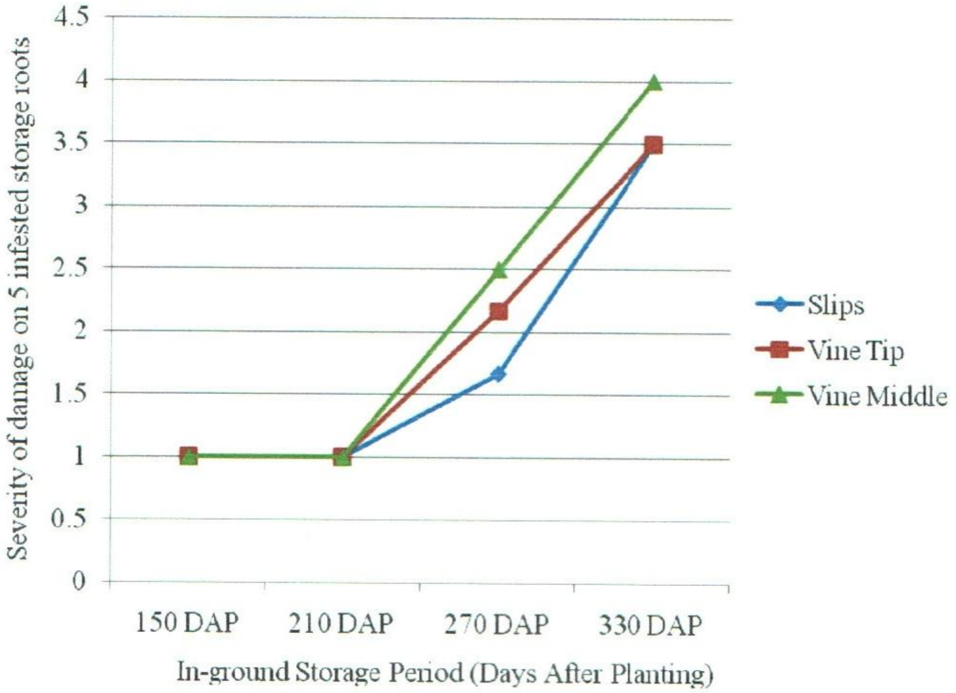

Figure 4. 15 Effect of Planting Material x In-ground storage period on severity of damage in storage roots (score 1-5) during season I

Table 4.9 Correlation coefficient among yield and infestation parameters on storage roots harvested at Bukura agricultural college, Kakamega during season I (June, 2009 – May, 2010)

	Mkt Root No.	Mkt Root Wt	Total Root No.	Total root Wt	Infested Root No	Severity	Density	% Weevil Incidence	Yield
1.Number market roots	1								
2.Market root weight	0.642*	1							
3.Total root number	0.814*	0.360*	1						
4.Weight of roots	0.683*	0.993*	0.443	1					
5.Infested root number	0.390*	-0.103	0.501*	-0.053	1				
6.Severity root damage	0.433	0.1	0.524*	0.152	0.760*	1			
7.Weevil root density	0.371	-0.148	0.528*	-0.096	0.941*	0.727*	1		
8.% Weevil incidence	0.243*	-0.185	0.291	-0.155	0.941*	0.673*	0.900*	1	
9.Total root yield	0.683*	0.993*	0.443*	1*	-0.053	0.152	-0.096	-0.155	1

* Significant $P<0.05$

Table 4.10 Correlation coefficient among yield and infestation parameters on storage roots harvested at Bukura agricultural college, Kakamega during season II (September, 2009 – August, 2010)

	Mkt Root No.	Mkt Root Wt	Total Root No.	Total root Wt	Infested Root No	Severity	Density	% Weevil Incidence	Yield
1.Number market roots	1								
2.Market root weight	0.531*	1							
3.Total root number	0.905*	0.339*	1						
4.Weight of roots	0.586*	0.984*	0.428*	1					
5.Infested root number	0.464*	-0.08	0.528*	-0.007	1				
6.Severity root damage	0.159	-0.109	0.192	-0.056	0.829*	1			
7.Weevil root density	0.567	0.036*	0.578*	0.094	0.879*	0.685*	1		
8.% Weevil incidence	0.077	-0.266*	0.155	-0.208	0.852*	0.889*	0.622*	1	
9.Total root yield	0.589*	0.984*	0.431*	1*	-0.005	-0.055	0.096	-0.208	1

* Significant P<0.05

4.3 Effect of variety, type of planting material and in-ground storage period on weevil infestation on crowns of sweetpotatoes

Number of crowns at harvest did not significantly (P<0.05) differ between varieties during both seasons (Table 4.11 and 4.12). However, crown number significantly (P<0.05) differed among in-ground storage period during season II (Table 4.12). There was a high number of crowns harvested at 330 DAP with no significant difference at 150 DAP and the lowest number of crowns was harvested at 210 DAP and 270 DAP with no significant difference at 150 DAP. Planting material differed significantly (P<0.05) during season I where vine tips had higher numbers of crowns with no significant difference from vine middle while the sprouts significantly (P<0.05) gave lower number of crowns at harvest with no significant difference from vine middle.

Number of infested crowns significantly (P<0.05) differed between varieties, in-ground storage period and planting materials during both seasons (Table 4.11 and 4.12). SPK 004 significantly (P<0.05) had high number of infested crowns in season II (Table 4.8) with no significant difference during season I. In-ground storage period during season I had the highest number of infested crowns at 210 DAP with no significant difference on further delay to harvest. But during season II, number of infested crowns increased significantly (P<0.05) with increase in-ground storage period. Vine middle significantly (P<0.05) had the higher number of infested crowns than vine tips and sprouts. During season I, planting material did not significantly (P<0.05) differ.

Weevil incidence on crowns significantly (P<0.05) differed during both seasons. SPK 004 significantly (P<0.05) had high weevil incidence during both seasons. These results are in line with the findings of Hartemink *et al.*, (2000) indicating crown damage high over both seasons. With highest percent weevil incidence of 33% during season II (Table 4.12). 210 DAP significantly (P<0.05) gave high percent weevil incidence during both seasons. Therefore, harvests at 150 DAP to avoid high percent weevil incidence on crowns. Planting materials during season II significantly (P<0.05) differed. Vine middle had high percent weevil incidence than vine tip and sprout which did not differ.

During season I, severity of damage between varieties did not differ but during season II, SPK 004 significantly ($P<0.05$) was more damaged than SPK 013. There was a significant ($P<0.05$) variety by planting material interaction on severity of weevil damage on crowns of sweetpotatoes during season II. All varieties were damaged but SPK 004 was significantly ($P<0.05$) more damaged than SPK 013. All types of planting material for SPK 013 had no damage score while SPK 004 sprouts and vine middle had slight damage with vine tips having severe damage (figure 4.20). In-ground storage at 210 DAP significantly ($P<0.05$) had more crowns damaged during both seasons while vine middle was significantly ($P<0.05$) more damaged than vine tips and sprouts during both seasons.

Crown weevil density significantly ($P<0.05$) differed between varieties, in-ground storage period and planting material during both seasons. SPK 004 significantly ($P<0.05$) had high density of weevil in crowns than SPK 013. The crown density was highest during season I, where crown weevil density increased with delay to harvest (Table 4.11) but during season II, 330 DAP gave the highest crown weevil density with no significant difference 150 DAP, 210 DAP and 270 DAP. During season I, there was significantly ($P<0.05$) variety by in-ground storage period interaction effect. All varieties weevil density on crowns increased with delay to harvest. SPK 004 was significantly ($P<0.05$) with higher densities which increased linearly at a higher rate than SPK 013(Figure 4.17). But during season II, SPK 004 weevil density increased linearly with storage period up 270 DAP and then short up while SPK 013 significantly ($P<0.05$) had lower density that decreased with storage period up to 270 DAP and then increased (figure 4.18)

Planting materials significantly ($P<0.05$) differed during both season. During season I and II, vine middle gave higher crown density which significantly ($P<0.05$) differed from vine tip and sprouts (Table 4.11). There was also significantly ($P<0.05$) variety by planting material crown weevil density interaction during season II. SPK 013 had a low weevil density on all types of planting material used while SPK 004, vine middle used as planting material had significantly ($P<0.05$) high crown weevil density than the vine tips and sprouts which were not significantly ($P<0.05$) different (figure 4.19).

Table 4.11 Effect of variety, in-ground storage period and type of planting material on yield and damage of sweetpotato crowns by *Cylas spp* at Bukura agricultural college, Kakamega during season I (June, 2009 – May, 2010)

Factor	No at harvest 10^3/ha	No Infested 10^3/ha	% Weevil Incidence	severity of damage (score 1-5)	Weevil density on 5 infested crowns
Variety					
SPK 013	26.9 a	8.7 a	32.5 (5.1) b	2.4 a	6.8 (2.4) b
SPK 004	24.9 a	11.5 a	46.3 (6.2) a	2.6 a	61.4 (6.9) a
Lsd (0.05)	ns	ns	1.0	ns	1.9
In-ground storage period					
150 DAP	24.7 a	0.9 b	3.5 (1.8) b	1.0 b	3.4 (1.2) c
210 DAP	25.6 a	11.0 a	43.1 (6.1) b	2.9 a	23.7 (2.3) b
270 DAP	27.5 a	14.0 a	51.0 (7.2) a	2.9 a	47.7 (3.1) ab
330 DAP	25.7 a	15.4 a	59.8 (7.5) a	3.4 a	61.5 (3.4) a
Lsd (0.05)	ns	4.3	1.4	0.7	0.9
Type of Planting material					
Sprouts	24.9 b	10.6 a	42.4 (6.0) a	2.2 b	28.5 (4.2) b
Vine tips	26.9 a	9.7 a	35.9 (5.6) a	2.5 b	31.3 (4.4) b
Vine Middle	25.8 ab	10.3 a	39.8 (5.9) a	2.9 a	41.7 (5.3) a
Lsd (0.05)	1.5	ns	ns	0.3	0.8
CV%	12.6	19.6	21.8	26.8	29.0

ns = not significant

Means followed by similar letters are not significantly ($P<0.05$) different using LSD

Figures in parenthesis are means of the original values

Table 4.12 Effect of variety, in-ground storage period and type of planting material on yield and damage of sweetpotato crowns by *Cylas sppat* Bukura agricultural college, Kakamega during season II (September, 2009 – August, 2010)

Factor	No at harvest10^3/ha	NoInfested10^3 /ha	% Weevil Incidence	severity of damage (score 1-5)	Weevil density on 5 infested crowns
Variety					
SPK 013	25.2 a	5.3 b	29.2 (5.0) b	0.6 (1.9) b	0.7 (1.3) b
SPK 004	24.7 a	10.7 a	52.6 (7.2) a	1.5 (2.5) a	3.8 (2.0) a
Lsd (0.05)	ns	5.3	1.1	0.5	0.2
In-ground storage period					
150 DAP	25.6 ab	2.8 d	14.6 (3.5) b	0.2 (1.9) b	1.0 (1.3) b
210 DAP	23.5 b	6.4 c	53.9 (7.2) a	1.3 (2.0) a	1.5 (1.5) b
270 DAP	23.8 b	9.2 b	49.3 (5.7) a	1.0 (2.1) a	2.0 (1.8) a
330 DAP	27.1 a	12.3 a	57.8 (7.6) a	1.6 (2.4) a	4.5 (2.1) a
Lsd (0.05)	2.3	1.2	1.5	0.8	0.4
Type of Planting material					
Sprouts	25.2 a	7.6 b	36.0 (5.6) b	0.9 (2.3) ab	1.6 (1.5) b
Vine tips	25.1 a	8.9 b	38.6 (5.8) b	0.9 (2.0) b	1.4 (1.5) b
Vine Middle	24.6 a	11.8 a	48.2 (6.7) a	1.3 (2.5) a	3.7 (2.0) a
Lsd (0.05)	ns	1.6	0.8	0.3	0.1
CV%	13.8	25.1	34	38.3	15.4

ns = not significant

Means followed by similar letters are not significantly ($P<0.05$) different using LSD

Figures in parenthesis are means of the original values

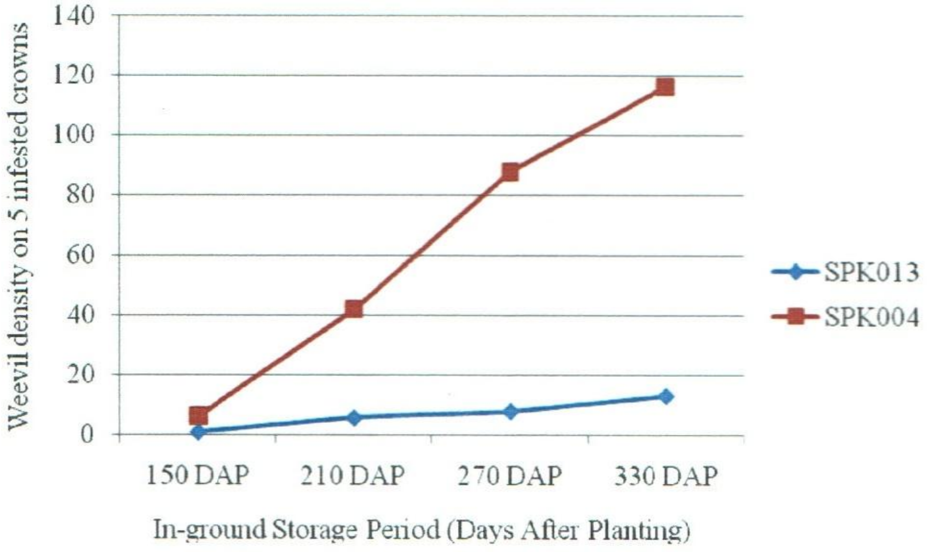

Figure 4. 16 Effect of Variety x In-ground storage period on weevil density on crowns during season I (June, 2009 – May, 2010)

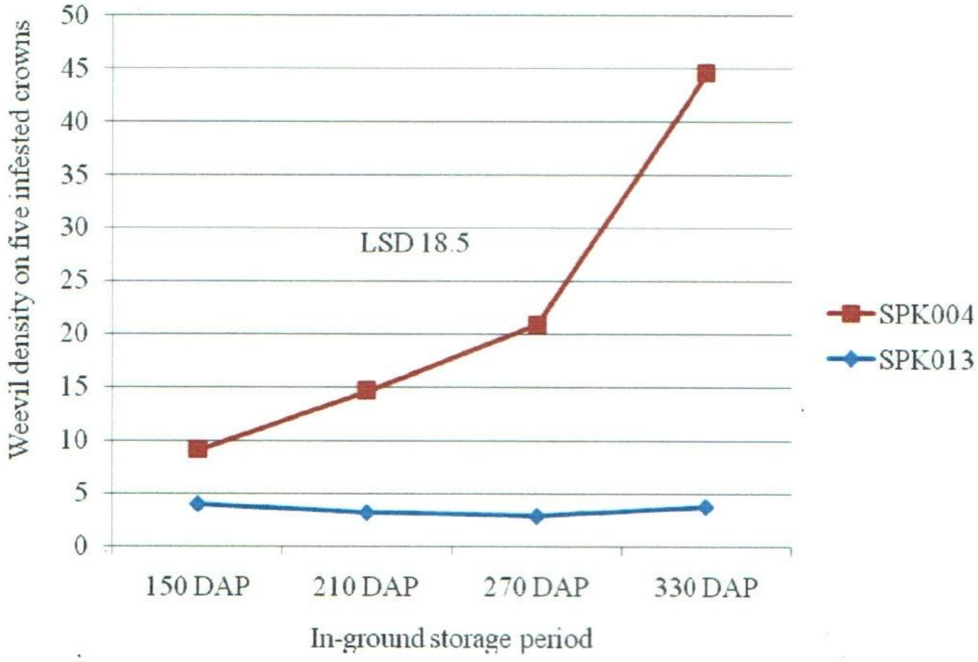

Figure 4. 17 Effect of variety x in-ground storage period on weevil density on crowns during season II (September, 2009 – August, 2010)

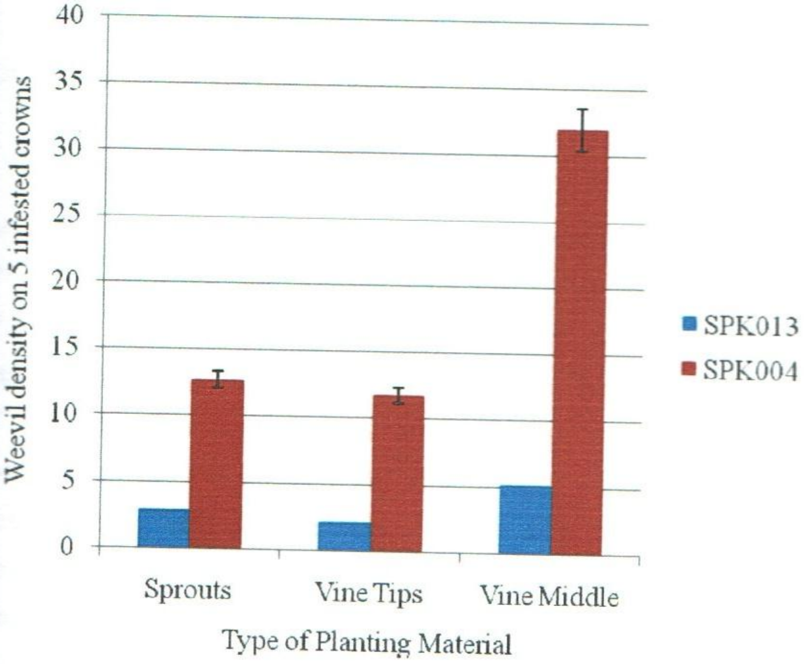

Figure 4. 18 Effect of Variety x Planting Material on weevil density of crowns during season II (September, 2009 – August, 2010)

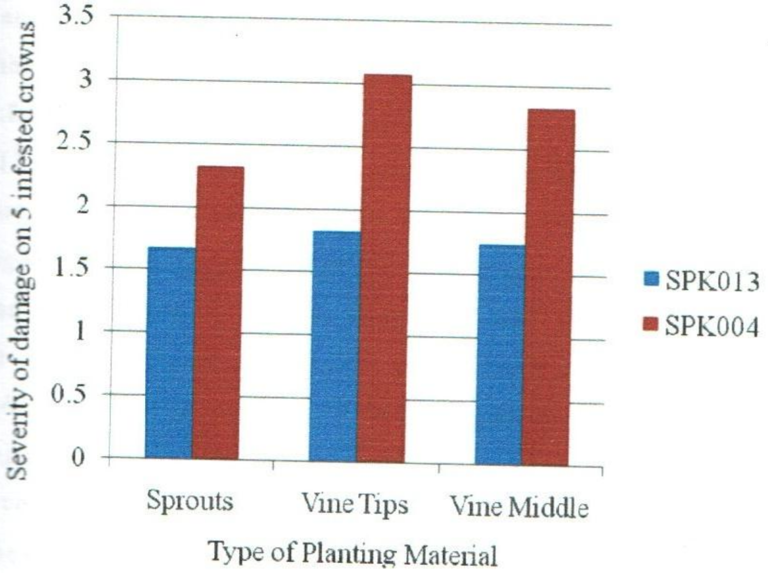

Figure 4. 19 Effect of Variety x Planting Material on severity of damage on crowns during season II (September, 2009 – August, 2010)

4.4 Across season analysis on yield and infestation of sweetpotato vines and storage roots by sweetpotato weevil cylas spp

4.4.1 Effect of season, variety, in-ground storage and type of planting material on yield of vines of sweetpotato during June, 2009 – August, 2010

Seasons did not differ on number of vines at harvest but significantly (P<0.05) differed on weight and yields of vines. Season I significantly (P<0.05) had higher weight and yield of vines than season II. SPK 013 significantly had higher number of vines at harvest, higher weight and yields of vines than SPK 004. In-ground storage period did not have an effect on number of vines at harvest but at 330 DAP significantly (P<0.05) had higher weight and yield of vine that did not differ from 270 DAP and 210 DAP. However, 150 DAP significantly (P<0.05) had lower yields and weight of vines (Table 4.13).

4.4.2 Effect of season, variety, in-ground storage and type of planting material on sweetpotato weevil infestation of vines of sweetpotato during June, 2009 – August, 2010

The seasons did not differ on infested number of vines and vine severity of damage but season I significantly (P<0.05) had higher weevil density in vines than during season II. SPK 004 significantly (P<0.05) had higher number of infested vines, severely damaged and higher weevil density in vines than SPK 013 (Table 4.13). There was a significant (P<0.05) season by variety interaction on weevil density of vines. Season I significantly (P<0.05) had higher weevil density on vines than season II. SPK 004 significantly (P<0.05) had higher weevil density than SPK 013 during both seasons (Figure 4.20). At 330 DAP weevil density significantly (P<0.05) were higher than 2701 DAP, 210 DAP while 150 DAP significantly (P<0.05) had lower. Weevil density in vines increased with delay to harvest. Infested vine number and severity of damage significantly (P<0.05) differed among in-ground storage. They were significantly (P<0.05) higher at 330 DAP and lower at 150 DAP but significantly (P<0.05) different from 270 DAP which did not differ from 210 DAP (table 4.13).

There was a significant ($P<0.05$) season by in-ground storage interaction on number of infested vines was seen where during both seasons, number of infested vines increased with delay to harvest. At 150 DAP, infested vines were low but increased at a high rate for both seasons to 210 DAP where season I the number increased at a decreasing rate while season II reduced at 270 DAP and then increased at 330 DAP (Figure 4.21). The reduction at 270 DAP was as a result of harvest in March the period presiding dry season when weevils gain entry to roots through cracks in the soil thus low infested vines. The vine middle significantly ($P<0.05$) had higher number of infested vines, vines severely damaged and with high weevil density in vines than vine tip and sprout. Vine tip significantly ($P<0.05$) had lower infested number of vines, lower damage and low weevil density in vines but not different from sprouts. However, sprouts had lower severity of damage in vines than vine tip and vine middle (Table 4.13).

4.4.3 Effect of season, variety, in-ground storage and type of planting material on yield of storage roots of sweetpotato during June, 2009 – August, 2010

Yield of storage roots did not differ between seasons. However, total number of storage roots significantly ($P<0.05$) differed between seasons. Season I significantly ($P<0.05$) had higher total number of storage roots than season II. This could have been as a result of well distributed rainfall during season II that led to production of more above ground biomas at the expense of storage roots. Total number and yield of storage roots significantly ($P<0.05$) differed between varieties. SPK 013 significantly ($P<0.05$) had higher yield of storage roots than SPK 004 which significantly ($P<0.05$) had higher total number of storage roots. This showed that, SPK 004 had many storage roots that were lighter in weight than SPK 013 (table 4.14). The yields and total number of storage roots were significantly ($P<0.05$) higher at 330 DAP but did not differ from 270 DAP and 210 DAP while 150 DAP had lower. Vine tip as 1 significantly ($P<0.05$) had higher number and yields of storage roots but yields did not differ from vine middle. However, sprouts significantly ($P<0.05$) had lower number and yields of storage roots but the yields did not differ from vine tips (table 4.14).

4.4.4 Effects of season, variety, in-ground storage and planting material on weevil infestation of storage roots of sweetpotato during June, 2009 – August, 2010

There was a significant (P<0.05) difference between seasons on infested number, severity of weevil damage and weevil density of storage roots. Season I significantly (P<0.05) had higher number of infested roots, severely damaged roots and higher weevil density on roots. During season I the amount of rainfall received was lower than during season II (Appendix 1). This showed that weevil infestation is higher during period of low rainfall.SPK 013 significantly (P<0.05) had low infested number of storage roots, low root damage and low weevil density in storage roots than SPK 004. In-ground storage at 330 DAP significantly (P<0.05) had higher number of infested roots, higher severely damaged storage roots and higher weevil density in storage roots with 150 DAP significantly (P<0.05) had the lower. Number infested, severity of damage and weevil density increased with delay to harvest (table 4.14). There was a significant season by in-ground storage period on severity of damage to storage roots. During season I severity of damage was significantly (P<0.05) higher than season II. Severity of damage on roots was significantly (P<0.05) low at 150 DAP and 210 DAP during both seasons which then increased at a high rate during season I and at a lower rate during season II on further delay to harvest (Figure 4.22). Therefore delay to harvest increase weevil infestation in sweetpotato. Vine tip as planting material significantly (P<0.05) had lower number infested, lower damage and lower weevil density in storage roots. However, vine middle had higher number infested, higher weevil damage and higher weevil density in storage roots. Sprouts had lower infested number, lower weevil density and severely damaged.

Table 4.13 Effect of season, variety, in-ground storage and type of planting material on yield and infestation by *cylas spp* on vines of sweetpotato during June, 2009 – August, 2010

Factor	Yield Parameters		Weevil Damage Parameters		
	Vine yield	Vine number	Infested vine number	Vine damage	Vine weevil density
Season					
I	31.93 a	10.35 a	4.07 a	1.18 a	6.98 a
II	42.59 b	9.99 a	4.07 a	1.03 a	2.23 b
Lsd	3.9	ns	ns	ns	1.2
Variety					
SPK 013	41.39 a	10.42 a	3.24 b	0.76 b	1.02 b
SPK 004	33.14 b	9.92 b	4.90 a	1.45 a	8.19 a
Lsd	3.9	0.4	0.5	0.1	1.2
In ground Storage					
150	28.49 b	10.06 a	0.92 c	0.14 c	0.79 d
210	40.73 a	9.81 a	4.56 b	1.25 b	3.11 c
270	39.56 a	10.25 a	4.58 b	1.23 b	5.82 b
330	40.28 a	10.56 a	6.22 a	1.81 a	8.71 a
Lsd	5.5	ns	0.8	0.2	1.7
Planting Material					
Sprout	37.25 a	10.02 a	3.83 b	0.98 c	3.63 b
Vine tip	37.59 a	10.40 a	3.88 b	1.00 b	3.83 b
Vine middle	36.95 a	10.08 a	4 50 a	1.34 a	6.35 a
Lsd	ns	ns	0.5	0.2	1.5
CV	23.4	11.8	31.1	42.1	58.0

ns = not significant

Means followed by similar letters are not significantly (P<0.05) different using LSD

Table 4.14 Effect of season, variety, in-ground storage and type of planting material on yield and infestation by *cylas spp* on storage roots of sweetpotato during June, 2009 – August, 2010

Factor	Yield Parameters			Weevil Damage Parameters		
	Number marketable root	Total number	Root yield	Infested root number	Root damage	Root weevil density
Season						
I	15.93 a	27.62 a	17.45 a	4.35 a	2.08 a	12.92 a
II	13.75 b	22.36 b	16.59 a	1.96 b	1.85 a	5.70 b
Lsd	2.1	2.9	ns	0.4	ns	1.4
Variety						
SPK 013	12.99 b	19.24 b	20.00 a	0.37 b	1.31 b	0.43 b
SPK 004	16.69 a	30.75 a	14.04 b	5.93 a	2.62 a	18.19 a
Lsd	2.1	2.9	2.5	0.4	0.3	1.4
In ground Storage						
150	9.36 c	18.28 c	9.58 b	0.31 d	1.00 c	0.57 d
210	14.03 b	23.69 b	17.26 a	2.08 c	1.25 c	7.18 c
270	17.50 a	28.28 a	20.41 a	4.22 b	2.53 b	11.67 b
330	18.47 a	29.72 a	20.84 a	6.00 a	3.08 a	17.82 a
Lsd	2.9	4.1	3.6	0.6	0.4	0.2
Planting Material						
Sprout	12.10 b	21.42 b	14.36 b	2.79 b	2.00 a	7.13 b
Vine tip	17.06 a	27.29 a	19.64 a	2.40 b	1.85 a	8.33 b
Vine middle	15.35 a	26.27 a	17.06 ab	4.27 a	2.04 a	12.46 a
Lsd	2.5	3.6	3.1	0.5	ns	1.7
CV	41.9	28.9	13.1	38.4		38.8

ns = not significant

Means followed by similar letters are not significantly ($P<0.05$) different using LSD

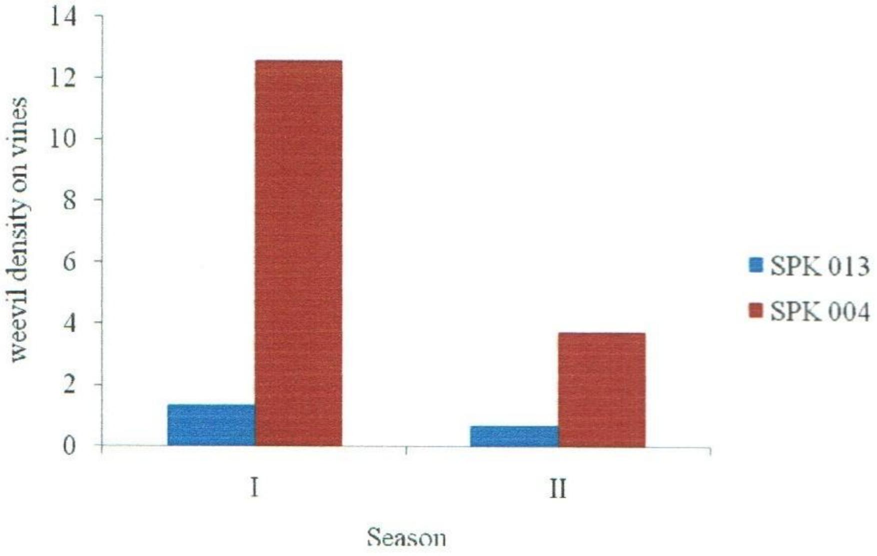

Figure 4. 20 Effect of season by variety on weevil density of vines

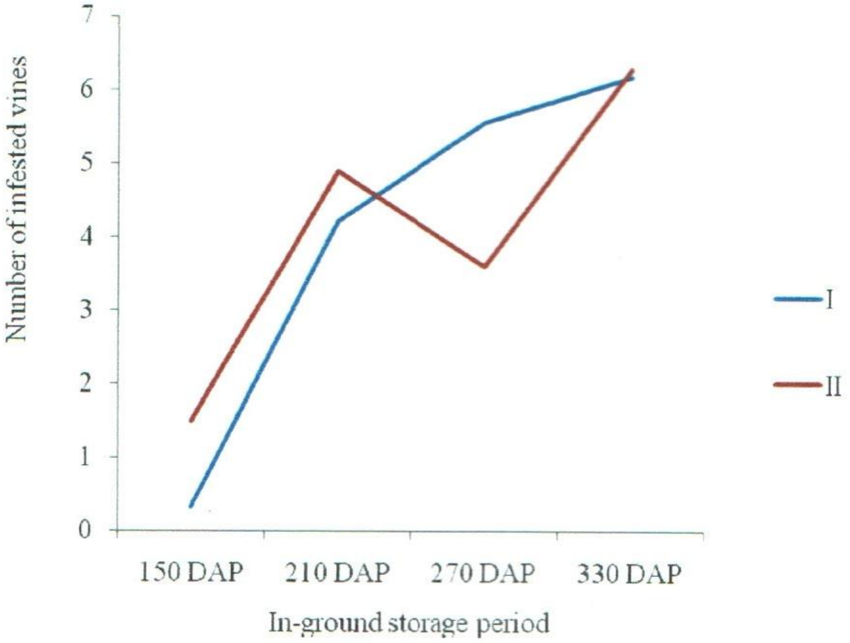

Figure 4. 21 Effect of season by in-ground storage period on number of infested vines

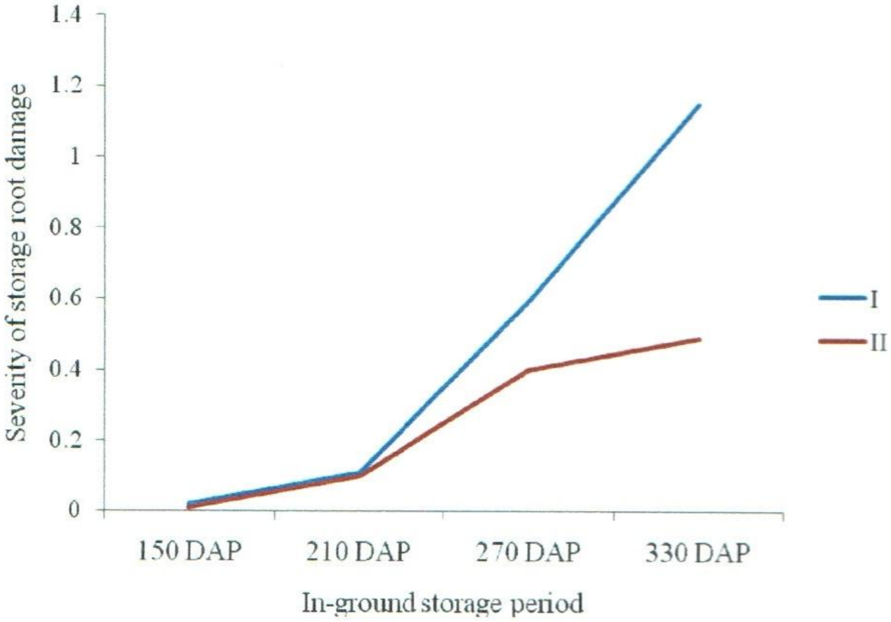

Figure 4. 22 Effect of season by in-ground storage period on severity of weevil damage on storage roots

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The results of the two experiments showed that, SPK 013significantly ($P<0.05$) had higher yields of vines and storage roots than SPK 004. The yields of vine of SPK 013 were 10 tones higher than SPK 004 during both seasons. SPK 013 significantly ($P<0.05$) had high yields of storage roots during season I than SPK 004 with no significant difference during season II despite the high yields of vines. SPK 004 was significantly ($P<0.05$) more susceptible to weevil damage during both seasons than SPK 013. This was as a result of high number of infested vines, crowns and storage roots of SPK 004 that had high weevil population. However, SPK 013 significantly ($P<0.05$) had low weevil population of less than one during both season.

Analysis of variance showed that, in-ground storage period of 330 DAP significantly ($P<0.05$) had high yields of vines and storage roots which did not significantly ($P<0.05$) differ from 210 DAP and 270 DAP during both seasons. The results showed that at 210 DAP there was high number of marketable storage roots, high total number of storage roots, high yield of marketable storage roots and high total yield of marketable roots during both seasons. Similarly at 210 DAP; there was low percent weevil incidence, low weevil damage low weevil density and low number of infested vines and storage roots during both seasons.

Use of vine tip as planting materials had higher yields for both vines and storage roots during both seasons. This was as a result of high total number and high total yield of vines and storage roots than the vine middle and the sprouts. Similarly, vine tips had lower infested number, low weevil incidence, low weevil damage and low weevil density which was not different from sprouts on vines and storage roots during both seasons.

There was significant interaction effect between varieties by in-ground storage period on severity of damage on storage roots, significant variety by in-ground storage period interaction on weevil density and significant variety by in-ground storage period on percent weevil incidence where both varieties increased with delay to harvest SPK 004 increasing higher than SPK 013 during both seasons. The results indicated that weevil infestation increase with delay to harvest and the increasing rate depends on susceptibility of the variety.

Similarly, there was significant type of planting material by in-ground storage period interaction on severity of damage, significant planting material by in-ground storage period significant interaction effects on weevil density which increased with delay to harvest were higher on vine middle than sprouts and vine tips. Therefore, vine tips seem to be less infested thus important to be used as planting material for susceptible varieties.

The results showed a positive and significant correlation of vine number with yield of vines and significantly ($P<0.05$) negative correlation of vine damage and crown damage with yield of vines. High vine number at harvest had high yields of vines while high vine and crown damage resulted in low yields of vine

Across season analysis indicated that SPK 013 had higher yields than SPK 004, storage period at 210 DAP had double yields at 150 DAP but with a little more damage than 150 DAP. Vine tip had higher yields but not different from vine middle with low weevil infestation while vine middle was highly infested. Sprouts had low infestation and low yields of both vines and storage roots.

5.2 RECOMMENDATIONS

1. Farmers should be advised to grow SPK 013 variety as a variety of choice when climatic conditions favour growth and development of weevils. However early planting should be recommended to allow SPK 013 escape weevil damage.
2. It is recommended that farmers use vine tips as planting material if they wish to reduce weevil damage on roots. However, uninfested vine middle is the next best alternative when you have inadequate planting material. Root sprout is the last choice of planting material and only if under very severe demand.
3. Farmers who wish to harvest roots and use their crop for seed for next season should be advised to harvest at 150 DAP, as crop has low weevil infestation. Farmers who wish to maximize root yield, should be encouraged to harvesting at 210 DAP, when weevil infestation is still relatively low. Therefore, sweetpotato crop should not be kept in the field beyond 210 DAP as this result in high weevil damage.

Way forward

There is a need to evaluate more sweetpotato varieties to quantify farmer's loss to sweetpotato weevil on yields and in-ground storage periods necessary to benefit farmers.

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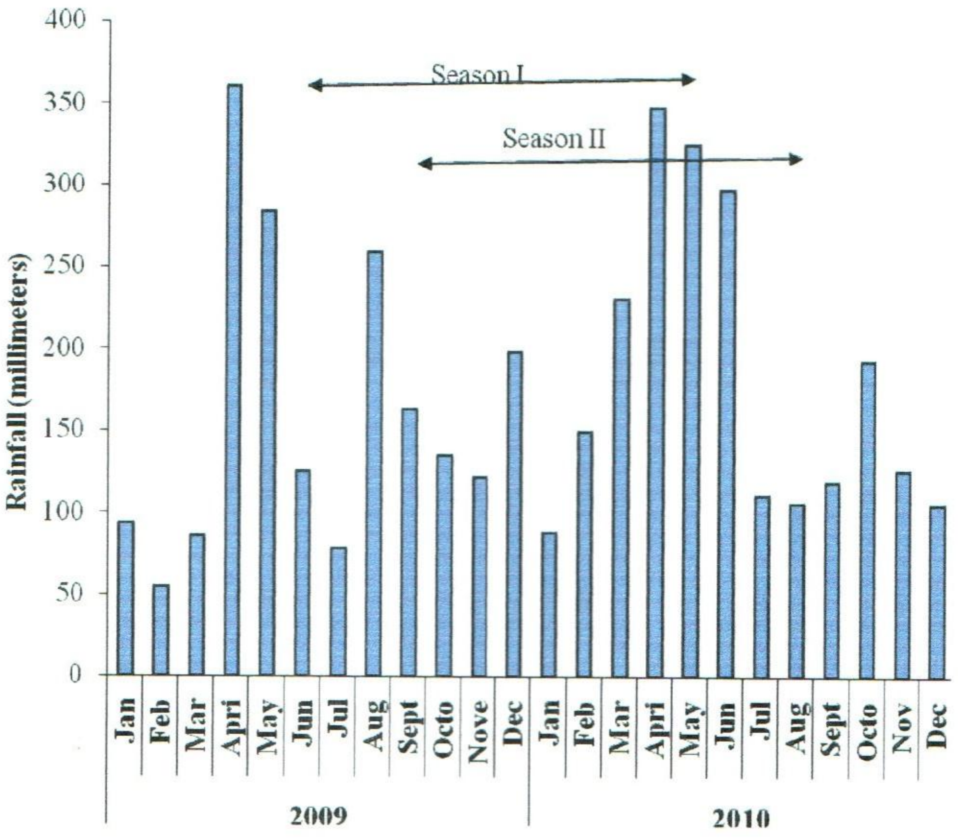
APPENDICES

Appendix 1. Rainfall (mm) for the period January 2009 to December 2010 at Bukura Institute metrological station, Kakamega district.

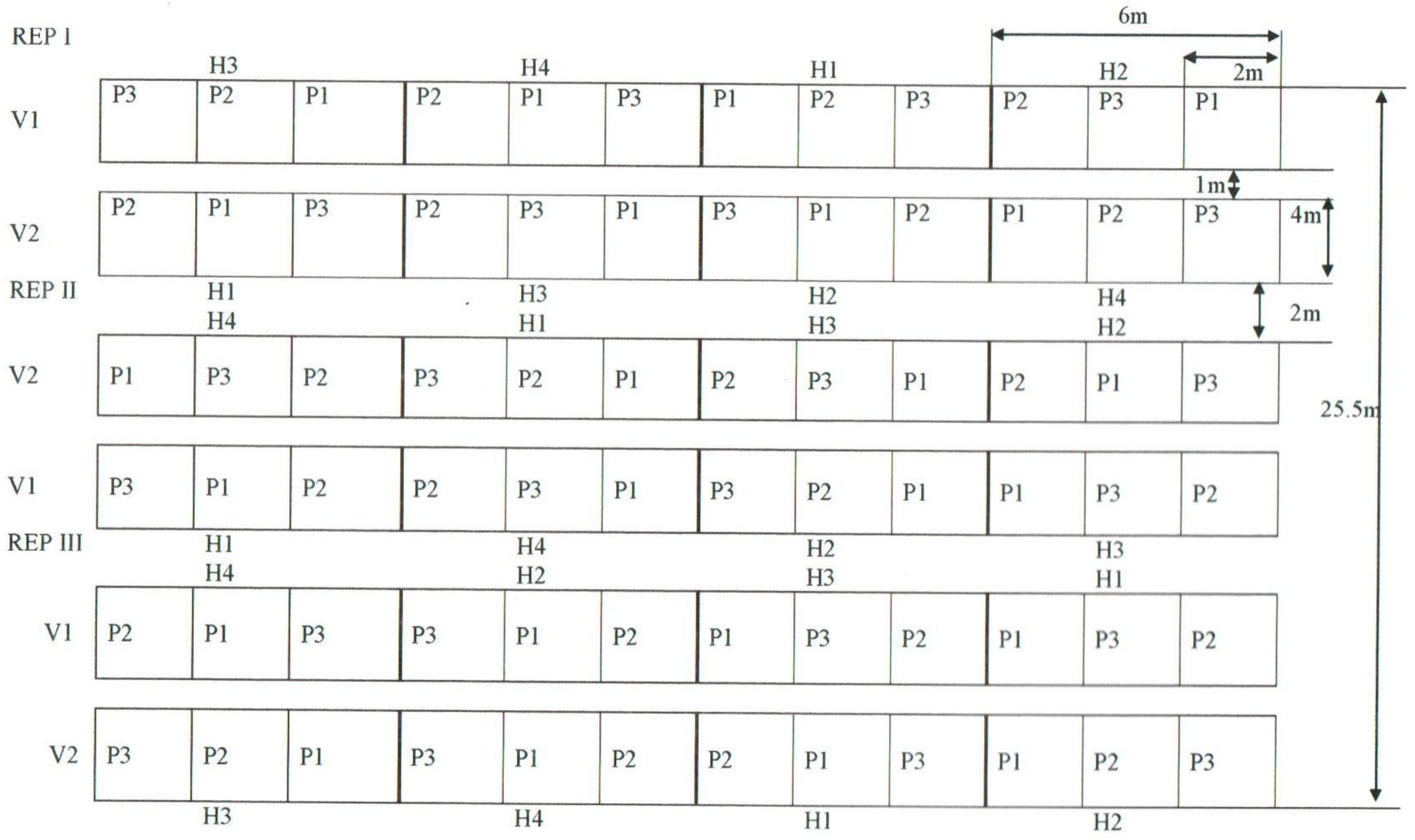
Month **Year**	Jan	Feb	Mar	Apri	May	June	July	Aug	Sep	Oct	Nov	Dec
2009 Total	92.7	29.5	132.4	332.8	284.5	105.7	90.9	245.3	157.6	132.7	123.7	203.4
Mean	**3.0**	**1.1**	**4.3**	**11.1**	**9.2**	**3.5**	**3.0**	**8.0**	**5.3**	**4.3**	**4.1**	**6.6**
2010 Total	88.0	173.2	265.6	344.1	322.4	297.2	110.7	105.8	118.9	192.7	125.8	105.2
Mean	**2.8**	**6.2**	**8.57**	**11.47**	**10.8**	**9.9**	**3.6**	**3.5**	**4**	**6.2**	**4.2**	**3.4**

Source: Bukura institute reg no.8934177



Rainfall data at Bukura Institute of Agriculture Metrological Station Reg No. 8934177 during period of January, 2009 to December, 2010

Appendix 2. Field Layout



Appendix 3. Record of planting and harvesting period of exploratory experiment at BukuraAgriculturalCollege during June, 2009 to August, 2010

Season	Date planted	Date harvested	Days/Months in field	
Season I	27/6/2009	20/11/2009	150	5
		20/1/2010	210	7
		17/3/2010	270	9
		13/5/2010	330	11
Season II	25/9/2009	23/2/2010	150	5
		27/4/2010	210	7
		29/6/2010	270	9
		31/8/2010	330	11

Appendix 4. Mean squares from analysis of variance for sweetpotato storage root yield, total number, weight, number infested, severity of damage and weevil density

Source of variation	Yield	Total number	Weight	Infested number	Severity	Density
Season (S)	95948718 *	765.4 ns	8.5 ns	203.1**	3.2 ns	1844.0**
Variety (V)	95148482 *	4246.7 *	181.8 *	1105.6**	17.0**	11266.1**
S x V	95579463 ns	521.4 ns	21.0 ns	162.6**	4.0 ns	1603.3**
In-ground Storage (H)	95266313 *	1185.0 **	136.9**	223.9**	3.9**	1934.8**
S x H	95716901 ns	127.9 ns	16.9 ns	38.9**	0.6 ns	194.3**
V x H	96090284 ns	299.5 ns	38.0 ns	167.3**	3.0**	1732.8**
S x V x H	95950938 ns	54.1 ns	16.1 ns	28.4**	0.6 ns	174.6**
Planting Material (Pm)	3227009 *	442.6 **	56.2**	45.8**	0.9 ns	359.8**
S x Pm	3167978 ns	6.1 ns	2.1 ns	7.9**	0.1 ns	5.5 ns
V x Pm	3159650 ns	52.9 **	10.2 ns	40. 3**	0.6 ns	305.3**
S x V x Pm	3172943 ns	87.1 ns	2.7 ns	5.0*	0.3 ns	12.3 ns
Pm x H	3166799 ns	45.6 ns	3.5 ns	4.6**	0.2 *	58.7**
S x Pm x H	3167151 ns	86.1 ns	3.6 ns	3.6*	0.3 ns	19.1 ns
V x Pm x H	3164132 ns	36.8 ns	3.2 ns	4.3*	0.3 ns	50.6**
S x V x Pm x H	3181021 ns	116.0*	9.0 ns	2.8 ns	0.2 ns	24.9 ns

Appendix 5. Mean squares from analysis of variance for sweetpotato vine and crown yield, total number, weight, number infested, severity of damage and weevil density

Source of variation	Vines						Crowns	
	Yield	Total number	Weight	Infested number	Severity damage	Density	Severity damage	Density
Season (S)	4926.9 *	4.7 ns	468.7 *	0.0 *	0.9 ns	810.4 **	6.3 *	20258.8**
Variety (V)	3109.0 *	9.0 ns	247.0 ns	98.3 ns	17.4 **	1846.1**	7.1 *	46153.4**
S x V	1.2 ns	3.4 ns	49.5 ns	14.1 ns	0.9 ns	600.3 **	2.8 ns	15006.3**
In-ground Storage (H)	1716.0**	3.6 ns	101.5 *	181.2 **	7.5 **	420.6 **	22.6 **	10515.4**
S x H	109.3 ns	8.5 *	42.5 ns	16.2 *	1.0 ns	144.7 **	2.3 ns	3616.3**
V x H	58.0 ns	0.3 ns	65.8 ns	9.4 *	1.5 ns	310.6 **	0.2 *	7765.0**
S x V x H	255.6 ns	0.8 ns	12.0 ns	3.5 ns	0.7 ns	82.9 *	0.8 ns	2071.3*
Planting Material (Pm)	3.1	1.9 ns	2.3 *	6.5 *	1.9 **	110.5 **	2.8 **	2763.4**
S x Pm	128.7 ns	2.3 ns	11.0 ns	4.1 ns	0.1 ns	4.0 ns	0.4 ns	100.7 ns
V x Pm	145.6 ns	2.5 ns	31.9 ns	3.3 *	1.3 **	57.6 **	0.6 ns	1441.1**
S x V x Pm	49.8 ns	0.8 ns	2.0 ns	0.0 ns	0.1 ns	0.6 ns	0.2 ns	15.4 ns
Pm x H	70.5 ns	1.8 ns	15.4 ns	4.4 *	0.8 **	5.2 ns	0.3 *	129.2 ns
S x Pm x H	83.8 ns	0.5 ns	15.0 ns	3.3 ns	0.3 ns	5.7 ns	0.4 ns	141.5 ns
V x Pm x H	122.1 ns	1.1 ns	17.0 ns	1.1 ns	0.1 ns	3.0 ns	0.1 ns	72.7 ns
S x V x Pm x H	60.6 ns	1.0 ns	5.9 ns	1.4 ns	0.1 ns	4.6 ns	0.1 ns	114.6 ns

Appendix 6. SAS Output

```
The SAS System       13:03 Thursday, February 11, 2013 260
The GLM Procedure
Class Level Information
Class        Levels  Values
sea              2  1 2
plot            72             101 102 103 104 105 106 107 108 109 110 111 112
113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133
134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154
155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172
Rep              3  1 2 3
Var              2  1 2
Pm               3  1 2 3
H                4  1 2 3 4
Number of Observations Read          144
Number of Observations Used          144
The SAS System       13:03 Thursday, February 11, 2013 261
The GLM Procedure
Dependent Variable: VN
                              Sum of
Source               DF      Squares      Mean Square    F Value     Pr > F
Model                79    176.6666667      2.2362869       1.57     0.0320
Error                64     91.3333333      1.4270833
Corrected Total     143    268.0000000

R-Square      Coeff Var       Root MSE        VN Mean
0.659204       11.75022       1.194606       10.16667
Source                 DF      Type IV SS      Mean Square     F Value     Pr > F
sea                     1      4.69444444      4.69444444        3.29     0.0744
Rep                     2      1.16666667      0.58333333        0.41     0.6662
Var                     1      9.00000000      9.00000000        6.31     0.0146
sea*Var                 1      3.36111111      3.36111111        2.36     0.1298
sea*Rep*Var             6     16.27777778      2.71296296        1.90     0.0942
H                       3     10.83333333      3.61111111        2.53     0.0649
sea*H                   3     25.58333333      8.52777778        5.98     0.0012
Var*H                   3      0.94444444      0.31481481        0.22     0.8818
sea*Var*H               3      2.25000000      0.75000000        0.53     0.6663
sea*Rep*Var*H          24     61.22222222      2.55092593        1.79     0.0341
Pm                      2      3.87500000      1.93750000        1.36     0.2646
sea*Pm                  2      4.51388889      2.25694444        1.58     0.2136
Var*Pm                  2      5.04166667      2.52083333        1.77     0.1792
sea*Var*Pm              2      1.51388889      0.75694444        0.53     0.5909
Pm*H                    6     10.29166667      1.71527778        1.20     0.3169
sea*Pm*H                6      3.20833333      0.53472222        0.37     0.8925
Var*Pm*H                6      6.68055556      1.11342593        0.78     0.5885
sea*Var*Pm*H            6      6.20833333      1.03472222        0.73     0.6310
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                 DF      Type IV SS      Mean Square     F Value     Pr > F
sea                     1      4.69444444      4.69444444        1.73     0.2364
Var                     1      9.00000000      9.00000000        5.01     0.0284
sea*Var                 1      3.36111111      3.36111111        1.24     0.3083
The SAS System       13:03 Thursday, February 11, 2013 262
The GLM Procedure
Dependent Variable: VN
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                     DF       Type IV SS       Mean Square      F Value      Pr > F
H              3      10.83333333       3.61111111         1.42      0.2626
sea*H          3      25.58333333       8.52777778         3.34      0.0360
Var*H          3       0.94444444       0.31481481         0.12      0.9454
sea*Var*H                 3        2.25000000        0.75000000         0.29      0.8293
The SAS System        13:03 Thursday, February 11, 2013 263
The GLM Procedure
Dependent Variable: MR
Sum of
Source          DF           Squares       Mean Square      F Value       Pr > F
Model                   79      7002.659722         88.641262         3.03      <.0001
```

```
Error            64     1874.666667        29.291667
Corrected Total     143     8877.326389
R-Square        Coeff Var        Root MSE        MR Mean
0.788825         36.46952        5.412178        14.84028
Source          DF         Type IV SS       Mean Square      F Value     Pr > F
sea                    1        171.173611        171.173611          5.84     0.0185
Rep                    2        944.763889        472.381944         16.13     <.0001
Var                    1        495.062500        495.062500         16.90     0.0001
sea*Var                1        162.562500        162.562500          5.55     0.0216
sea*Rep*Var            6        718.013889        119.668981          4.09     0.0016
H                      3       1834.076389        611.358796         20.87     <.0001
sea*H           3      110.687500         36.895833          1.26      0.2958
Var*H           3      150.687500         50.229167          1.71      0.1728
sea*Var*H              3         87.743056         29.247685          1.00     0.3994
sea*Rep*Var*H          24       1041.222222         43.384259          1.48     0.1081
Pm                     2        609.055556        304.527778         10.40     0.0001
sea*Pm                 2         16.888889          8.444444          0.29     0.7505
Var*Pm          2       57.166667         28.583333          0.98      0.3824
sea*Var*Pm             2         32.000000         16.000000          0.55     0.5818
Pm*H                   6        117.444444         19.574074          0.67     0.6755
sea*Pm*H               6        143.500000         23.916667          0.82     0.5612
Var*Pm*H               6         84.000000         14.000000          0.48     0.8223
sea*Var*Pm*H           6        226.611111         37.768519          1.29     0.2748
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                 DF        Type IV SS        Mean Square     F Value     Pr > F
sea             1      171.1736111       171.1736111         1.43      0.2768
Var             1      495.0625000       495.0625000         4.14      0.0882
sea*Var         1      162.5625000       162.5625000         1.36      0.2880
The SAS System         13:03 Thursday, February 11, 2013 266
The GLM Procedure
Dependent Variable: MR
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                 DF         Type IV SS       Mean Square     F Value     Pr > F
H                       3       1834.076389        611.358796        14.09      <.0001
sea*H                3       110.687500         36.895833          0.85     0.4800
Var*H                3       150.687500         50.229167          1.16     0.3463
sea*Var*H        3        87.743056         29.247685        0.67     0.5763
The SAS System         13:03 Thursday, February 11, 2013 269
The GLM Procedure
Dependent Variable: MRW
                                                 Sum of
Source                              DF          Squares       Mean Square      F Value      Pr > F
Model                               79      2005.813056        25.390039         4.90      <.0001
Error                               64       331.833333         5.184896
Corrected Total                     143     2337.646389
R-Square       Coeff Var            Root MSE         MRW Mean
0.858048        38.53035            2.277037         5.909722
Source                              DF       Type IV SS       Mean Square      F Value      Pr > F
sea                                  1        9.9225000        9.9225000         1.91      0.1714
Rep                                  2      368.6334722      184.3167361        35.55      <.0001
Var                                  1      283.9225000      283.9225000        54.76      <.0001
sea*Var                              1       29.3402778       29.3402778         5.66      0.0204
sea*Rep*Var                          6      184.1543056       30.6923843         5.92      <.0001
H                                    3      381.4247222      127.1415741        24.52      <.0001
sea*H                                3       65.6080556       21.8693519         4.22      0.0087
Var*H                                3       95.6791667       31.8930556         6.15      0.0010
sea*Var*H                            3       38.8691667       12.9563889         2.50      0.0675
sea*Rep*Var*H                       24      322.5255556       13.4385648         2.59      0.0013
Pm                                   2      101.6818056       50.8409028         9.81      0.0002
sea*Pm                               2        2.6862500        1.3431250         0.26      0.7726
Var*Pm                               2       20.8504167       10.4252083         2.01      0.1423
sea*Var*Pm                           2        4.2359722        2.1179861         0.41      0.6664
Pm*H                                 6       14.1765278        2.3627546         0.46      0.8383
sea*Pm*H                             6       19.7531944        3.2921991         0.63      0.7018
Var*Pm*H                             6       20.4445833        3.4074306         0.66      0.6842
sea*Var*Pm*H                         6       41.9045833        6.9840972         1.35      0.2497
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                              DF       Type IV SS       Mean Square      F Value      Pr > F
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sea                            1        9.9225000        9.9225000        0.32     0.5903
Var                            1      283.9225000      283.9225000        9.25     0.0228
sea*Var                        1       29.3402778       29.3402778        0.96     0.3660
The SAS System       13:03 Thursday, February 11, 2013 270
The GLM Procedure
Dependent Variable: MRW
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                        DF      Type IV SS      Mean Square     F Value     Pr > F
H                              3      381.4247222      127.1415741        9.46     0.0003
sea*H                          3       65.6080556       21.8693519        1.63     0.2093
Var*H                          3       95.6791667       31.8930556        2.37     0.0954
sea*Var*H                      3       38.8691667       12.9563889        0.96     0.4258
The SAS System       13:03 Thursday, February 11, 2013 271
The GLM Procedure
Dependent Variable: NMRN
Sum of
Source                        DF         Squares      Mean Square     F Value     Pr > F
Model                         79     5913.000000        74.848101        4.59     <.0001
Error                         64     1044.222222        16.315972
Corrected Total              143     6957.222222
R-Square      Coeff Var       Root MSE      NMRN Mean
0.849908      40.96195        4.039303       9.861111
Source                        DF      Type IV SS      Mean Square     F Value     Pr > F
sea                            1      336.111111       336.111111       20.60     <.0001
Rep                            2      583.847222       291.923611       17.89     <.0001
Var                            1     2040.027778      2040.027778      125.03     <.0001
sea*Var                        1       23.361111        23.361111        1.43     0.2359
sea*Rep*Var                    6      476.708333        79.451389        4.87     0.0004
H                              3       79.500000        26.500000        1.62     0.1925
sea*H                          3      398.055556       132.685185        8.13     0.0001
Var*H                          3      191.916667        63.972222        3.92     0.0124
sea*Var*H                      3      214.472222        71.490741        4.38     0.0072
sea*Rep*Var*H                 24      880.555556        36.689815        2.25     0.0053
Pm                             2       71.430556        35.715278        2.19     0.1203
sea*Pm                         2       17.763889         8.881944        0.54     0.5829
Var*Pm                         2       11.930556         5.965278        0.37     0.6952
sea*Var*Pm                     2       49.597222        24.798611        1.52     0.2265
Pm*H                           6      102.125000        17.020833        1.04     0.4061
sea*Pm*H                       6      163.236111        27.206019        1.67     0.1435
Var*Pm*H                       6      101.625000        16.937500        1.04     0.4092
sea*Var*Pm*H                   6      170.736111        28.456019        1.74     0.1252
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                        DF      Type IV SS      Mean Square     F Value     Pr > F
sea                            1      336.111111       336.111111        4.23     0.0854
Var                            1     2040.027778      2040.027778       25.68     0.0023
sea*Var                        1       23.361111        23.361111        0.29     0.6072
The SAS System       13:03 Thursday, February 11, 2013 272
The GLM Procedure
Dependent Variable: NMRN
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                        DF      Type IV SS      Mean Square     F Value     Pr > F
H                              3      79.5000000       26.5000000        0.72     0.5485
sea*H                          3     398.0555556      132.6851852        3.62     0.0276
Var*H                          3     191.9166667       63.9722222        1.74     0.1849
sea*Var*H                      3     214.4722222       71.4907407        1.95     0.1487
The SAS System       13:03 Thursday, February 11, 2013 279
The GLM Procedure
Dependent Variable: IVN
Sum of
Source                        DF         Squares      Mean Square     F Value     Pr > F
Model                         79     1057.048611        13.380362        8.31     <.0001
Error                         64      103.111111         1.611111
Corrected Total              143     1160.159722
R-Square      Coeff Var       Root MSE      IVN Mean
0.911123      31.13774        1.269296       4.076389
Source                        DF      Type IV SS      Mean Square     F Value     Pr > F
sea                            1       0.0069444        0.0069444        0.00     0.9479
Rep                            2      37.5972222       18.7986111       11.67     <.0001
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Var                          1      98.3402778       98.3402778        61.04      <.0001
sea*Var                      1      14.0625000       14.0625000         8.73      0.0044
sea*Rep*Var                  6      69.2361111       11.5393519         7.16      <.0001
H                            3     543.7430556      181.2476852       112.50      <.0001
sea*H                        3      48.4652778       16.1550926        10.03      <.0001
Var*H                        3      28.2430556        9.4143519         5.84      0.0014
sea*Var*H                    3      10.4097222        3.4699074         2.15      0.1021
sea*Rep*Var*H               24     118.0555556        4.9189815         3.05      0.0002
Pm                           2      13.0138889        6.5069444         4.04      0.0223
sea*Pm                       2       8.1805556        4.0902778         2.54      0.0869
Var*Pm                       2       6.5138889        3.2569444         2.02      0.1408
sea*Var*Pm                   2       0.1250000        0.0625000         0.04      0.9620
Pm*H                         6      26.1527778        4.3587963         2.71      0.0210
sea*Pm*H                     6      19.7638889        3.2939815         2.04      0.0724
Var*Pm*H                     6       6.6527778        1.1087963         0.69      0.6598
sea*Var*Pm*H                 6       8.4861111        1.4143519         0.88      0.5163
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                      DF      Type IV SS      Mean Square      F Value      Pr > F
sea                          1      0.00694444       0.00694444         0.00      0.9812
Var                          1     98.34027778      98.34027778         8.52      0.0267
sea*Var                      1     14.06250000      14.06250000         1.22      0.3119
The SAS System       13:03 Thursday, February 11, 2013 280
The GLM Procedure
Dependent Variable: IVN
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                      DF      Type IV SS      Mean Square      F Value      Pr > F
H                            3     543.7430556      181.2476852        36.85      <.0001
sea*H                        3      48.4652778       16.1550926         3.28      0.0381
Var*H                        3      28.2430556        9.4143519         1.91      0.1543
sea*Var*H                    3      10.4097222        3.4699074         0.71      0.5581
The SAS System       13:03 Thursday, February 11, 2013 286
The GLM Procedure
Dependent Variable: CS
Sum of
Source                      DF         Squares      Mean Square      F Value      Pr > F
Model                       79     133.3055556        1.6874121         7.71      <.0001
Error                       64      14.0000000        0.2187500
Corrected Total            143     147.3055556
R-Square     Coeff Var      Root MSE      CS Mean
0.904959      20.16462      0.467707      2.319444
Source                      DF      Type IV SS      Mean Square      F Value      Pr > F
sea                          1      6.25000000       6.25000000        28.57      <.0001
Rep                          2      2.05555556       1.02777778         4.70      0.0125
Var                          1      7.11111111       7.11111111        32.51      <.0001
sea*Var                      1      2.77777778       2.77777778        12.70      0.0007
sea*Rep*Var                  6      3.27777778       0.54629630         2.50      0.0311
H                            3     67.80555556      22.60185185       103.32      <.0001
sea*H                        3      6.80555556       2.26851852        10.37      <.0001
Var*H                        3      0.72222222       0.24074074         1.10      0.3555
sea*Var*H                    3      2.50000000       0.83333333         3.81      0.0141
sea*Rep*Var*H               24     20.00000000       0.83333333         3.81      <.0001
Pm                           2      5.68055556       2.84027778        12.98      <.0001
sea*Pm                       2      0.87500000       0.43750000         2.00      0.1437
Var*Pm                       2      1.26388889       0.63194444         2.89      0.0629
sea*Var*Pm                   2      0.34722222       0.17361111         0.79      0.4566
Pm*H                         6      1.98611111       0.33101852         1.51      0.1881
sea*Pm*H                     6      2.56944444       0.42824074         1.96      0.0849
Var*Pm*H                     6      0.40277778       0.06712963         0.31      0.9311
sea*Var*Pm*H                 6      0.87500000       0.14583333         0.67      0.6768
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                      DF      Type IV SS      Mean Square      F Value      Pr > F
sea                          1      6.25000000       6.25000000        11.44      0.0148
Var                          1      7.11111111       7.11111111        13.02      0.0113
sea*Var                      1      2.77777778       2.77777778         5.08      0.0650
The SAS System       13:03 Thursday, February 11, 2013 285
The GLM Procedure
Dependent Variable: CS
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
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Source                      DF      Type IV SS     Mean Square    F Value    Pr > F
H                            3     67.80555556     22.60185185      27.12    <.0001
sea*H                        3      6.80555556      2.26851852       2.72    0.0667
Var*H                        3      0.72222222      0.24074074       0.29    0.8330
sea*Var*H                    3      2.50000000      0.83333333       1.00    0.4098
The SAS System       13:03 Thursday, February 11, 2013 286
The GLM Procedure
Dependent Variable: CD
Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F
Model                       79     187040.7778       2367.6048      13.25    <.0001
Error                       64      11437.1111        178.7049
Corrected Total            143     198477.8889
R-Square     Coeff Var       Root MSE      CD Mean
0.942376      58.05186       13.36805      23.02778
Source                      DF      Type IV SS     Mean Square    F Value    Pr > F
sea                          1     20258.77778     20258.77778     113.36    <.0001
Rep                          2      1179.51389       589.75694       3.30    0.0432
Var                          1     46153.36111     46153.36111     258.27    <.0001
sea*Var                      1     15006.25000     15006.25000      83.97    <.0001
sea*Rep*Var                  6      5409.81944       901.63657       5.05    0.0003
H                            3     31546.22222     10515.40741      58.84    <.0001
sea*H                        3     10848.88889      3616.29630      20.24    <.0001
Var*H                        3     23294.97222      7764.99074      43.45    <.0001
sea*Var*H                    3      6213.86111      2071.28704      11.59    <.0001
sea*Rep*Var*H               24     15739.55556       655.81481       3.67    <.0001
Pm                           2      5526.76389      2763.38194      15.46    <.0001
sea*Pm                       2       201.34722       100.67361       0.56    0.5721
Var*Pm                       2      2882.18056      1441.09028       8.06    0.0008
sea*Var*Pm                   2        30.87500        15.43750       0.09    0.9173
Pm*H                         6       775.40278       129.23380       0.72    0.6325
sea*Pm*H                     6       849.15278       141.52546       0.79    0.5796
Var*Pm*H                     6       435.98611        72.66435       0.41    0.8720
sea*Var*Pm*H                 6       687.84722       114.64120       0.64    0.6966
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                      DF      Type IV SS     Mean Square    F Value    Pr > F
sea                          1     20258.77778     20258.77778      22.47    0.0032
Var                          1     46153.36111     46153.36111      51.19    0.0004
sea*Var                      1     15006.25000     15006.25000      16.64    0.0065
The SAS System       13:03 Thursday, February 11, 2013 287
The GLM Procedure
Dependent Variable: CD
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                      DF      Type IV SS     Mean Square    F Value    Pr > F
H                            3     31546.22222     10515.40741      16.03    <.0001
sea*H                        3     10848.88889      3616.29630       5.51    0.0050
Var*H                        3     23294.97222      7764.99074      11.84    <.0001
sea*Var*H                    3      6213.86111      2071.28704       3.16    0.0431
The SAS System       13:03 Thursday, February 11, 2013 288
The GLM Procedure
Dependent Variable: IRN
Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F
Model                       79     3242.381944       41.042809      28.08    <.0001
Error                       64       93.555556        1.461806
Corrected Total            143     3335.937500
R-Square     Coeff Var       Root MSE      IRN Mean
0.971955      38.43343       1.209052      3.145833
Source                      DF      Type IV SS     Mean Square    F Value    Pr > F
sea                          1      203.062500      203.062500     138.91    <.0001
Rep                          2        5.791667        2.895833       1.98    0.1463
Var                          1     1105.562500     1105.562500     756.30    <.0001
sea*Var                      1      162.562500      162.562500     111.21    <.0001
sea*Rep*Var                  6        9.208333        1.534722       1.05    0.4020
H                            3      671.743056      223.914352     153.18    <.0001
sea*H                        3      116.631944       38.877315      26.60    <.0001
Var*H                        3      502.020833      167.340278     114.48    <.0001
sea*Var*H                    3       85.243056       28.414352      19.44    <.0001
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sea*Rep*Var*H               24        91.444444        3.810185        2.61      0.0012
Pm                           2        91.541667       45.770833       31.31      <.0001
sea*Pm                       2        15.875000        7.937500        5.43      0.0066
Var*Pm                       2        80.541667       40.270833       27.55      <.0001
sea*Var*Pm                   2        10.041667        5.020833        3.43      0.0383
Pm*H                         6        27.402778        4.567130        3.12      0.0095
sea*Pm*H                     6        21.513889        3.585648        2.45      0.0338
Var*Pm*H                     6        25.625000        4.270833        2.92      0.0140
sea*Var*Pm*H                 6        16.569444        2.761574        1.89      0.0963

Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                      DF      Type IV SS      Mean Square    F Value    Pr > F
sea                          1      203.062500      203.062500      132.31    <.0001
Var                          1     1105.562500     1105.562500      720.37    <.0001
sea*Var                      1      162.562500      162.562500      105.92    <.0001
The SAS System       13:03 Thursday, February 11, 2013 289
The GLM Procedure
Dependent Variable: IRN
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                      DF      Type IV SS      Mean Square    F Value    Pr > F
H                            3     671.7430556     223.9143519       58.77    <.0001
sea*H                        3     116.6319444      38.8773148       10.20    0.0002
Var*H                        3     502.0208333     167.3402778       43.92    <.0001
sea*Var*H                    3      85.2430556      28.4143519        7.46    0.0011
The GLM Procedure
Dependent Variable: Rdmg
Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F
Model                       79     288.2222222       3.6483826       4.73    <.0001
Error                       64      49.3333333       0.7708333
Corrected Total            143     337.5555556
R-Square     Coeff Var      Root MSE     Rdmg Mean
0.853851      45.15280      0.877971      1.944444
Source                      DF      Type IV SS     Mean Square    F Value    Pr > F
sea                          1       2.2500000       2.2500000       2.92    0.0924
Rep                          2       0.7222222       0.3611111       0.47    0.6281
Var                          1      61.3611111      61.3611111      79.60    <.0001
sea*Var                      1       0.0000000       0.0000000       0.00    1.0000
sea*Rep*Var                  6       7.7222222       1.2870370       1.67    0.1429
H                            3     111.1666667      37.0555556      48.07    <.0001
sea*H                        3      12.8055556       4.2685185       5.54    0.0019
Var*H                        3      46.2500000      15.4166667      20.00    <.0001
sea*Var*H                    3       3.0555556       1.0185185       1.32    0.2752
sea*Rep*Var*H               24      22.2222222       0.9259259       1.20    0.2753
Pm                           2       1.0555556       0.5277778       0.68    0.5079
sea*Pm                       2       0.5000000       0.2500000       0.32    0.7242
Var*Pm                       2       1.3888889       0.6944444       0.90    0.4113
sea*Var*Pm                   2       4.1666667       2.0833333       2.70    0.0747
Pm*H                         6       1.8333333       0.3055556       0.40    0.8787
sea*Pm*H                     6       1.6111111       0.2685185       0.35    0.9083
Var*Pm*H                     6       5.1666667       0.8611111       1.12    0.3624
sea*Var*Pm*H                 6       4.9444444       0.8240741       1.07    0.3904
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                      DF      Type IV SS      Mean Square    F Value    Pr > F
sea                          1      2.25000000      2.25000000        1.75    0.2343
Var                          1     61.36111111     61.36111111       47.68    0.0005
sea*Var                      1      0.00000000      0.00000000        0.00    1.0000
The SAS System       13:03 Thursday, February 11, 2013 297
The GLM Procedure
Dependent Variable: Rdmg
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                      DF      Type IV SS      Mean Square    F Value    Pr > F
H                            3     111.1666667      37.0555556       40.02    <.0001
sea*H                        3      12.8055556       4.2685185        4.61    0.0110
Var*H                        3      46.2500000      15.4166667       16.65    <.0001
sea*Var*H                    3       3.0555556       1.0185185        1.10    0.3684
The SAS System       13:03 Thursday, February 11, 2013 302
The GLM Procedure
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Dependent Variable: YV
Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F
Model                       79     31448.04715       398.07655       5.35    <.0001
Error                       64      4759.25111        74.36330
Corrected Total            143     36207.29826
R-Square     Coeff Var      Root MSE      YV Mean
0.868555      23.46286      8.623416      36.75347
Source                      DF      Type IV SS     Mean Square    F Value    Pr > F
sea                          1     4926.870069     4926.870069      66.25    <.0001
Rep                          2     4997.050139     2498.525069      33.60    <.0001
Var                          1     3108.991736     3108.991736      41.81    <.0001
sea*Var                      1        1.228403        1.228403       0.02    0.8981
sea*Rep*Var                  6     4747.572083      791.262014      10.64    <.0001
H                            3     5148.234097     1716.078032      23.08    <.0001
sea*H                        3      327.885764      109.295255       1.47    0.2311
Var*H                        3      174.111875       58.037292       0.78    0.5092
sea*Var*H                    3      766.827431      255.609144       3.44    0.0219
sea*Rep*Var*H               24     4573.046667      190.543611       2.56    0.0015
Pm                           2        6.296806        3.148403       0.04    0.9586
sea*Pm                       2      257.485139      128.742569       1.73    0.1852
Var*Pm                       2      291.145972      145.572986       1.96    0.1496
sea*Var*Pm                   2       99.680972       49.840486       0.67    0.5151
Pm*H                         6      422.891528       70.481921       0.95    0.4676
sea*Pm*H                     6      502.683194       83.780532       1.13    0.3571
Var*Pm*H                     6      732.654583      122.109097       1.64    0.1501
sea*Var*Pm*H                 6      363.390694       60.565116       0.81    0.5627
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                      DF      Type IV SS     Mean Square    F Value    Pr > F
sea                          1     4926.870069     4926.870069       6.23    0.0468
Var                          1     3108.991736     3108.991736       4.93    0.0147
sea*Var                      1        1.228403        1.228403       0.00    0.9698
The SAS System       13:03 Thursday, February 11, 2013 303
The GLM Procedure
Dependent Variable: YV
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                      DF      Type IV SS     Mean Square    F Value    Pr > F
H                            3     5148.234097     1716.078032       9.01    0.0004
sea*H                        3      327.885764      109.295255       0.57    0.6379
Var*H                        3      174.111875       58.037292       0.30    0.8218
sea*Var*H                    3      766.827431      255.609144       1.34    0.2844
The SAS System       13:03 Thursday, February 11, 2013 304
The GLM Procedure
Dependent Variable: WV
Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F
Model                       79     4310.504444       54.563347       4.28    <.0001
Error                       64      814.975556       12.733993
Corrected Total            143     5125.480000
R-Square     Coeff Var      Root MSE      WV Mean
0.840995      23.42542      3.568472      15.23333
Source                      DF      Type IV SS     Mean Square    F Value    Pr > F
sea                          1     468.7225000     468.7225000      36.81    <.0001
Rep                          2     935.1379167     467.5689583      36.72    <.0001
Var                          1     247.0136111     247.0136111      19.40    <.0001
sea*Var                      1      49.4677778      49.4677778       3.88    0.0531
sea*Rep*Var                  6     758.7415278     126.4569213       9.93    <.0001
H                            3     304.5072222     101.5024074       7.97    0.0001
sea*H                        3     127.6080556      42.5360185       3.34    0.0246
Var*H                        3     197.3325000      65.7775000       5.17    0.0029
sea*Var*H                    3      35.8838889      11.9612963       0.94    0.4270
sea*Rep*Var*H               24     772.9050000      32.2043750       2.53    0.0017
Pm                           2       4.5679167       2.2839583       0.18    0.8362
sea*Pm                       2      21.8754167      10.9377083       0.86    0.4284
Var*Pm                       2      63.7634722      31.8817361       2.50    0.0898
sea*Var*Pm                   2       4.0393056       2.0196528       0.16    0.8537
Pm*H                         6      92.3798611      15.3966435       1.21    0.3133
sea*Pm*H                     6      89.4390278      14.9065046       1.17    0.3332
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Var*Pm*H                           6     101.8754167       16.9792361        1.33      0.2555
sea*Var*Pm*H                       6      35.2440278        5.8740046        0.46      0.8343
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                            DF     Type IV SS      Mean Square     F Value     Pr > F
sea                                1     468.7225000      468.7225000        5.71      0.0025
Var                                1     247.0136111      247.0136111        5.95      0.0117
sea*Var                            1      49.4677778       49.4677778        0.39      0.5547
The SAS System       13:03 Thursday, February 11, 2013 305
The GLM Procedure
Dependent Variable: WV
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                            DF     Type IV SS      Mean Square     F Value     Pr > F
H                                  3     304.5072222      101.5024074        3.15      0.0434
sea*H                              3     127.6080556       42.5360185        1.32      0.2908
Var*H                              3     197.3325000       65.7775000        2.04      0.1347
sea*Var*H                          3      35.8838889       11.9612963        0.37      0.7743
The SAS System       13:03 Thursday, February 11, 2013 306
The GLM Procedure
Dependent Variable: VI
Sum of
Source                            DF         Squares     Mean Square     F Value     Pr > F
Model                             79      98354.5686       1244.9945        7.28     <.0001
Error                             64      10942.3889        170.9748
Corrected Total                  143     109296.9575
R-Square      Coeff Var       Root MSE        VI Mean
0.899884       32.40913       13.07573       40.34583
Source                            DF     Type IV SS      Mean Square     F Value     Pr > F
sea                                1        44.00111         44.00111        0.26     0.6137
Rep                                2      2684.10042       1342.05021        7.85     0.0009
Var                                1     13102.61778      13102.61778       76.63     <.0001
sea*Var                            1       697.84028        697.84028        4.08     0.0475
sea*Rep*Var                        6      6787.07125       1131.17854        6.62     <.0001
H                                  3     48534.15472      16178.05157       94.62     <.0001
sea*H                              3      3503.24500       1167.74833        6.83     0.0005
Var*H                              3      3132.85944       1044.28648        6.11     0.0010
sea*Var*H                          3       424.18139        141.39380        0.83     0.4839
sea*Rep*Var*H                     24      9657.35944        402.38998        2.35     0.0035
Pm                                 2      1118.95875        559.47938        3.27     0.0444
sea*Pm                             2      1405.90681        702.95340        4.11     0.0209
Var*Pm                             2       850.50097        425.25049        2.49     0.0911
sea*Var*Pm                         2       113.41347         56.70674        0.33     0.7190
Pm*H                               6      3541.49069        590.24845        3.45     0.0051
sea*Pm*H                           6      1292.95708        215.49285        1.26     0.2882
Var*Pm*H                           6       756.88847        126.14808        0.74     0.6211
sea*Var*Pm*H                       6       707.02153        117.83692        0.69     0.6590
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                            DF     Type IV SS      Mean Square     F Value     Pr > F
sea                                1        44.00111         44.00111        0.04     0.8502
Var                                1     13102.61778      13102.61778       11.58     0.0144
sea*Var                            1       697.84028        697.84028        0.62     0.4621
The SAS System       13:03 Thursday, February 11, 2013 307
The GLM Procedure
Dependent Variable: VI
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                            DF     Type IV SS      Mean Square     F Value     Pr > F
H                                  3     48534.15472      16178.05157       40.20     <.0001
sea*H                              3      3503.24500       1167.74833        2.90     0.0556
Var*H                              3      3132.85944       1044.28648        2.60     0.0759
sea*Var*H                          3       424.18139        141.39380        0.35     0.7885
The SAS System       13:03 Thursday, February 11, 2013 308
The GLM Procedure
Dependent Variable: VS
Sum of
Source                            DF         Squares     Mean Square     F Value     Pr > F
Model                             79     116.7977778       1.4784529        6.76     <.0001
Error                             64      14.0044444       0.2188194
Corrected Total                  143     130.8022222
R-Square      Coeff Var       Root MSE        VS Mean
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0.892934      42.10033      0.467781      1.111111

Source                        DF      Type IV SS      Mean Square     F Value     Pr > F
sea                            1      0.87111111       0.87111111        3.98     0.0503
Rep                            2      4.03013889       2.01506944        9.21     0.0003
Var                            1     17.36111111      17.36111111       79.34     <.0001
sea*Var                        1      0.87111111       0.87111111        3.98     0.0503
sea*Rep*Var                    6      3.37208333       0.56201389        2.57     0.0272
H                              3     52.45833333      17.48611111       79.91     <.0001
sea*H                          3      3.10722222       1.03574074        4.73     0.0048
Var*H                          3      4.39277778       1.46425926        6.69     0.0005
sea*Var*H                      3      2.04500000       0.68166667        3.12     0.0322
sea*Rep*Var*H                 24     13.58666667       0.56611111        2.59     0.0013
Pm                             2      3.89930556       1.94965278        8.91     0.0004
sea*Pm                         2      0.13847222       0.06923611        0.32     0.7299
Var*Pm                         2      2.57347222       1.28673611        5.88     0.0045
sea*Var*Pm                     2      0.10263889       0.05131944        0.23     0.7916
Pm*H                           6      4.68291667       0.78048611        3.57     0.0041
sea*Pm*H                       6      1.92819444       0.32136574        1.47     0.2032
Var*Pm*H                       6      0.72763889       0.12127315        0.55     0.7649
sea*Var*Pm*H                   6      0.64958333       0.10826389        0.49     0.8099
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                        DF      Type IV SS      Mean Square     F Value     Pr > F
sea                            1      0.87111111       0.87111111        1.55     0.2596
Var                            1     17.36111111      17.36111111       30.89     0.0014
sea*Var                        1      0.87111111       0.87111111        1.55     0.2596
The SAS System       13:03 Thursday, February 11, 2013 309
The GLM Procedure
Dependent Variable: VS
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                        DF      Type IV SS      Mean Square     F Value     Pr > F
H                              3     52.45833333      17.48611111       30.89     <.0001
sea*H                          3      3.10722222       1.03574074        1.83     0.1687
Var*H                          3      4.39277778       1.46425926        2.59     0.0766
sea*Var*H                      3      2.04500000       0.68166667        1.20     0.3295
The SAS System       13:03 Thursday, February 11, 2013 310
The GLM Procedure
Dependent Variable: VD
Sum of
Source                        DF         Squares      Mean Square     F Value     Pr > F
Model                         79     7481.631111        94.704191       13.25     <.0001
Error                         64      457.484444         7.148194
Corrected Total              143     7939.115556
R-Square      Coeff Var       Root MSE        VD Mean
0.942376      58.05186        2.673611        4.605556
Source                        DF      Type IV SS      Mean Square     F Value     Pr > F
sea                            1      810.351111       810.351111      113.36     <.0001
Rep                            2       47.180556        23.590278        3.30     0.0432
Var                            1     1846.134444      1846.134444      258.27     <.0001
sea*Var                        1      600.250000       600.250000       83.97     <.0001
sea*Rep*Var                    6      216.392778        36.065463        5.05     0.0003
H                              3     1261.848889       420.616296       58.84     <.0001
sea*H                          3      433.955556       144.651852       20.24     <.0001
Var*H                          3      931.798889       310.599630       43.45     <.0001
sea*Var*H                      3      248.554444        82.851481       11.59     <.0001
sea*Rep*Var*H                 24      629.582222        26.232593        3.67     <.0001
Pm                             2      221.070556       110.535278       15.46     <.0001
sea*Pm                         2        8.053889         4.026944        0.56     0.5721
Var*Pm                         2      115.287222        57.643611        8.06     0.0008
sea*Var*Pm                     2        1.235000         0.617500        0.09     0.9173
Pm*H                           6       31.016111         5.169352        0.72     0.6325
sea*Pm*H                       6       33.966111         5.661019        0.79     0.5796
Var*Pm*H                       6       17.439444         2.906574        0.41     0.8720
sea*Var*Pm*H                   6       27.513889         4.585648        0.64     0.6966
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                        DF      Type IV SS      Mean Square     F Value     Pr > F
sea                            1      810.351111       810.351111       22.47     0.0032
Var                            1     1846.134444      1846.134444       51.19     0.0004
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sea*Var                          1        600.250000        600.250000        16.64     0.0065
The SAS System        13:03 Thursday, February 11, 2013 311
The GLM Procedure
Dependent Variable: VD
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                          DF       Type IV SS       Mean Square    F Value     Pr > F
H                                3      1261.848889        420.616296      16.03     <.0001
sea*H                            3       433.955556        144.651852       5.51     0.0050
Var*H                            3       931.798889        310.599630      11.84     <.0001
sea*Var*H                        3       248.554444         82.851481       3.16     0.0431
The SAS System        13:03 Thursday, February 11, 2013 312
The GLM Procedure
Dependent Variable: TRN
Sum of
Source                          DF          Squares       Mean Square    F Value     Pr > F
Model                           79      21597.55556         273.38678       5.39     <.0001
Error                           64       3246.44444          50.72569
Corrected Total                143      24844.00000
R-Square       Coeff Var        Root MSE        TRN Mean
0.869327       28.87377         7.122197        24.66667
Source                          DF       Type IV SS       Mean Square    F Value     Pr > F
sea                              1       765.444444        765.444444      15.09     0.0002
Rep                              2      3038.375000       1519.187500      29.95     <.0001
Var                              1      4246.694444       4246.694444      83.72     <.0001
sea*Var                          1       521.361111        521.361111      10.28     0.0021
sea*Rep*Var                      6      2349.958333        391.659722       7.72     <.0001
H                                3      3554.944444       1184.981481      23.36     <.0001
sea*H                            3       383.833333        127.944444       2.52     0.0656
Var*H                            3       898.583333        299.527778       5.90     0.0013
sea*Var*H                        3       162.250000         54.083333       1.07     0.3698
sea*Rep*Var*H                   24      2791.888889        116.328704       2.29     0.0044
Pm                               2       885.125000        442.562500       8.72     0.0004
sea*Pm                           2        12.180556          6.090278       0.12     0.8871
Var*Pm                           2       105.847222         52.923611       1.04     0.3582
sea*Var*Pm                       2       174.180556         87.090278       1.72     0.1878
Pm*H                             6       273.430556         45.571759       0.90     0.5017
sea*Pm*H                         6       516.708333         86.118056       1.70     0.1360
Var*Pm*H                         6       221.041667         36.840278       0.73     0.6301
sea*Var*Pm*H                     6       695.708333        115.951389       2.29     0.0462
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                          DF       Type IV SS       Mean Square    F Value     Pr > F
sea                              1       765.444444        765.444444       5.95     0.0116
Var                              1      4246.694444       4246.694444      10.84     0.0166
sea*Var                          1       521.361111        521.361111       1.33     0.2925
The SAS System        13:03 Thursday, February 11, 2013 313
The GLM Procedure
Dependent Variable: TRN
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                          DF       Type IV SS       Mean Square    F Value     Pr > F
H                                3      3554.944444       1184.981481      10.19     0.0002
sea*H                            3       383.833333        127.944444       1.10     0.3685
Var*H                            3       898.583333        299.527778       2.57     0.0775
sea*Var*H                        3       162.250000         54.083333       0.46     0.7094
The SAS System        13:03 Thursday, February 11, 2013 316
The GLM Procedure
Dependent Variable: YR

                                             Sum of
Source                          DF          Squares       Mean Square    F Value     Pr > F
Model                           79       4603772171          58275597      18.41     <.0001
Error                           64        202640607           3166259
Corrected Total                143       4806412778
R-Square       Coeff Var        Root MSE        YR Mean
0.957840       213.6409         1779.399        832.8924
Source                          DF       Type IV SS       Mean Square    F Value     Pr > F
sea                              1         95948718          95948718      30.30     <.0001
Rep                              2        191839427          95919714      30.29     <.0001
Var                              1         95148482          95148482      30.05     <.0001
sea*Var                          1         95579463          95579463      30.19     <.0001
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sea*Rep*Var                 6      574479692       95746615      30.24    <.0001
H                           3      285798938       95266313      30.09    <.0001
sea*H                       3      287150702       95716901      30.23    <.0001
Var*H                       3      288270853       96090284      30.35    <.0001
sea*Var*H                   3      287852814       95950938      30.30    <.0001
sea*Rep*Var*H              24     2300173300       95840554      30.27    <.0001
Pm                          2        6454018        3227009       6.02    0.0366
sea*Pm                      2        6335957        3167978       1.00    0.3734
Var*Pm                      2        6319299        3159650       1.00    0.3743
sea*Var*Pm                  2        6345887        3172943       1.00    0.3728
Pm*H                        6       19000791        3166799       1.00    0.4331
sea*Pm*H                    6       19002908        3167151       1.00    0.4330
Var*Pm*H                    6       18984792        3164132       1.00    0.4336
sea*Var*Pm*H                6       19086129        3181021       1.00    0.4302
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                     DF    Type IV SS     Mean Square    F Value    Pr > F
sea                         1    95948718.37    95948718.37       1.00    0.3554
Var                         1    95148481.93    95148481.93       2.99    0.0357
sea*Var                     1    95579463.43    95579463.43       1.00    0.3563
The SAS System        13:03 Thursday, February 11, 2013 317
The GLM Procedure
Dependent Variable: YR
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                     DF    Type IV SS     Mean Square    F Value    Pr > F
H                           3    285798937.8     95266312.6       4.99    0.0125
sea*H                       3    287150702.2     95716900.7       1.00    0.4104
Var*H                       3    288270853.4     96090284.5       1.00    0.4087
sea*Var*H                   3    287852814.2     95950938.1       1.00    0.4093
The SAS System        13:03 Thursday, February 11, 2013 318

The GLM Procedure
Dependent Variable: RW
                                 Sum of
Source                     DF       Squares    Mean Square    F Value    Pr > F
Model                      79   2053.559722      25.994427       4.62    <.0001
Error                      64    359.826667       5.622292
Corrected Total           143   2413.386389
R-Square     Coeff Var     Root MSE     RW Mean
0.850904      34.44056     2.371137    6.884722
Source                     DF    Type IV SS    Mean Square    F Value    Pr > F
sea                         1     8.5069444      8.5069444       1.51    0.2232
Rep                         2   421.3572222    210.6786111      37.47    <.0001
Var                         1   181.8002778    181.8002778      32.34    <.0001
sea*Var                     1    21.0069444     21.0069444       3.74    0.0577
sea*Rep*Var                 6   148.5916667     24.7652778       4.40    0.0009
H                           3   410.6791667    136.8930556      24.35    <.0001
sea*H                       3    50.7791667     16.9263889       3.01    0.0365
Var*H                       3   113.9147222     37.9715741       6.75    0.0005
sea*Var*H                   3    48.3391667     16.1130556       2.87    0.0434
sea*Rep*Var*H              24   389.7777778     16.2407407       2.89    0.0004
Pm                          2   112.3276389     56.1638194       9.99    0.0002
sea*Pm                      2     4.1634722      2.0817361       0.37    0.6920
Var*Pm                      2    20.3634722     10.1817361       1.81    0.1718
sea*Var*Pm                  2     5.3476389      2.6738194       0.48    0.6237
Pm*H                        6    21.0929167      3.5154861       0.63    0.7094
sea*Pm*H                    6    21.7870833      3.6311806       0.65    0.6932
Var*Pm*H                    6    19.4648611      3.2441435       0.58    0.7472
sea*Var*Pm*H                6    54.2595833      9.0432639       1.61    0.1593
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                     DF    Type IV SS    Mean Square    F Value    Pr > F
sea                         1     8.5069444      8.5069444       0.34    0.5792
Var                         1   181.8002778    181.8002778       7.34    0.0351
sea*Var                     1    21.0069444     21.0069444       0.85    0.3926
The SAS System        13:03 Thursday, February 11, 2013 319
The GLM Procedure
Dependent Variable: RW
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                     DF    Type IV SS    Mean Square    F Value    Pr > F
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H                            3     410.6791667     136.8930556       8.43    0.0005
sea*H                        3      50.7791667      16.9263889       1.04    0.3918
Var*H                        3     113.9147222      37.9715741       2.34    0.0989
sea*Var*H                    3      48.3391667      16.1130556       0.99    0.4133
The SAS System       13:03 Thursday, February 11, 2013 320
The GLM Procedure
Dependent Variable: RI
Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F
Model                       79     30053.93778       380.42959       8.75    <.0001
Error                       64      2782.71778        43.47997
Corrected Total            143     32836.65556
R-Square     Coeff Var      Root MSE       RI Mean
0.915256      61.94719      6.593934      10.64444
Source                      DF      Type IV SS     Mean Square    F Value    Pr > F
sea                          1      1173.06250      1173.06250      26.98    <.0001
Rep                          2      1046.00014       523.00007      12.03    <.0001
Var                          1     10757.14694     10757.14694     247.40    <.0001
sea*Var                      1      1305.61778      1305.61778      30.03    <.0001
sea*Rep*Var                  6       588.07486        98.01248       2.25    0.0491
H                            3      6087.74389      2029.24796      46.67    <.0001
sea*H                        3       380.82917       126.94306       2.92    0.0407
Var*H                        3      3884.39694      1294.79898      29.78    <.0001
sea*Var*H                    3       485.19611       161.73204       3.72    0.0157
sea*Rep*Var*H               24      2465.97389       102.74891       2.36    0.0033
Pm                           2       588.08722       294.04361       6.76    0.0022
sea*Pm                       2        22.88167        11.44083       0.26    0.7695
Var*Pm                       2       528.89056       264.44528       6.08    0.0038
sea*Var*Pm                   2        41.81722        20.90861       0.48    0.6205
Pm*H                         6       203.13278        33.85546       0.78    0.5897
sea*Pm*H                     6       214.99500        35.83250       0.82    0.5555
Var*Pm*H                     6       256.68389        42.78065       0.98    0.4436
sea*Var*Pm*H                 6        23.40722         3.90120       0.09    0.9971
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                      DF      Type IV SS     Mean Square    F Value    Pr > F
sea                          1      1173.06250      1173.06250      11.97    0.0135
Var                          1     10757.14694     10757.14694     109.75    <.0001
sea*Var                      1      1305.61778      1305.61778      13.32    0.0107
The SAS System       13:03 Thursday, February 11, 2013 321
The GLM Procedure
Dependent Variable: RI
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                      DF      Type IV SS     Mean Square    F Value    Pr > F
H                            3     6087.743889     2029.247963      19.75    <.0001
sea*H                        3      380.829167      126.943056       1.24    0.3186
Var*H                        3     3884.396944     1294.798981      12.60    <.0001
sea*Var*H                    3      485.196111      161.732037       1.57    0.2216
The SAS System       13:03 Thursday, February 11, 2013 322
The GLM Procedure
Dependent Variable: RS
Sum of
Source                      DF         Squares     Mean Square    F Value    Pr > F
Model                       79     73.25381944      0.92726354       3.07    <.0001
Error                       64     19.31555556      0.30180556
Corrected Total            143     92.56937500
R-Square     Coeff Var      Root MSE       RS Mean
0.791340      138.0611      0.549368      0.397917
Source                      DF      Type IV SS     Mean Square    F Value    Pr > F
sea                          1      3.15062500      3.15062500      10.44    0.0019
Rep                          2      2.00666667      1.00333333       3.32    0.0423
Var                          1     17.01562500     17.01562500      56.38    <.0001
sea*Var                      1      3.96673611      3.96673611      13.14    0.0006
sea*Rep*Var                  6      4.31555556      0.71925926       2.38    0.0385
H                            3     11.68465278      3.89488426      12.91    <.0001
sea*H                        3      1.93576389      0.64525463       2.14    0.1041
Var*H                        3      9.11187500      3.03729167      10.06    <.0001
sea*Var*H                    3      1.71965278      0.57321759       1.90    0.1386
sea*Rep*Var*H               24      8.40222222      0.35009259       1.16    0.3114
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Pm                            2     1.81291667      0.90645833      3.00    0.0567
sea*Pm                        2     0.23291667      0.11645833      0.39    0.6814
Var*Pm                        2     1.10791667      0.55395833      1.84    0.1678
sea*Var*Pm                    2     0.54347222      0.27173611      0.90    0.4115
Pm*H                          6     1.15597222      0.19266204      0.64    0.6991
sea*Pm*H                      6     2.03819444      0.33969907      1.13    0.3577
Var*Pm*H                      6     1.61875000      0.26979167      0.89    0.5049
sea*Var*Pm*H                  6     1.43430556      0.23905093      0.79    0.5795
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                       DF    Type IV SS     Mean Square    F Value    Pr > F
sea                           1     3.15062500      3.15062500      6.38    0.0213
Var                           1    17.01562500     17.01562500     23.66    0.0028
sea*Var                       1     3.96673611      3.96673611      5.52    0.0572
The SAS System      13:03 Thursday, February 11, 2013 323
The GLM Procedure
Dependent Variable: RS
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                       DF    Type IV SS     Mean Square    F Value    Pr > F
H                             3    11.68465278      3.89488426     11.13    <.0001
sea*H                         3     1.93576389      0.64525463      1.84    0.1663
Var*H                         3     9.11187500      3.03729167      8.68    0.0004
sea*Var*H                     3     1.71965278      0.57321759      1.64    0.2071
The SAS System      13:03 Thursday, February 11, 2013 324
The GLM Procedure
Dependent Variable: RD
Sum of
Source                       DF        Squares     Mean Square    F Value    Pr > F
Model                        79    30131.27382       381.40853      29.38    <.0001
Error                        64      830.71111        12.97986
Corrected Total             143    30961.98493
R-Square     Coeff Var      Root MSE       RD Mean
0.973170      38.84084      3.602757      9.275694
Source                       DF    Type IV SS     Mean Square    F Value    Pr > F
sea                           1    1843.98674      1843.98674     142.07    <.0001
Rep                           2      56.38931        28.19465       2.17    0.1223
Var                           1   11266.05340     11266.05340     867.96    <.0001
sea*Var                       1    1603.33507      1603.33507     123.52    <.0001
sea*Rep*Var                   6     174.16458        29.02743       2.24    0.0507
H                             3    5804.31743      1934.77248     149.06    <.0001
sea*H                         3     582.90687       194.30229      14.97    <.0001
Var*H                         3    5198.48688      1732.82896     133.50    <.0001
sea*Var*H                     3     523.74299       174.58100      13.45    <.0001
sea*Rep*Var*H                24     792.43500        33.01813       2.54    0.0016
Pm                            2     719.67681       359.83840      27.72    <.0001
sea*Pm                        2      11.00681         5.50340       0.42    0.6563
Var*Pm                        2     610.59347       305.29674      23.52    <.0001
sea*Var*Pm                    2      24.59681        12.29840       0.95    0.3931
Pm*H                          6     352.20819        58.70137       4.52    0.0007
sea*Pm*H                      6     114.32042        19.05340       1.47    0.2034
Var*Pm*H                      6     303.60708        50.60118       3.90    0.0022
sea*Var*Pm*H                  6     149.44597        24.90766       1.92    0.0912
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var as an Error Term
Source                       DF    Type IV SS     Mean Square    F Value    Pr > F
sea                           1    1843.98674      1843.98674      63.53    0.0002
Var                           1   11266.05340     11266.05340     388.12    <.0001
sea*Var                       1    1603.33507      1603.33507      55.24    0.0003
The SAS System      13:03 Thursday, February 11, 2013 325
The GLM Procedure
Dependent Variable: RD
Tests of Hypotheses Using the Type IV MS for sea*Rep*Var*H as an Error Term
Source                       DF    Type IV SS     Mean Square    F Value    Pr > F
H                             3   5804.317431     1934.772477      58.60    <.0001
sea*H                         3    582.906875      194.302292       5.88    0.0037
Var*H                         3   5198.486875     1732.828958      52.48    <.0001
sea*Var*H                     3    523.742986      174.580995       5.29    0.0061
```